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Understanding the economic and environmental impact of food consumption and waste through life cycle thinking

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Abstract

Current food systems need to be urgently redesigned as they are unable to feed a growing global population ensuring social justice and environmental sustainability contemporaneously. The building blocks for a transition to more sustainable food systems should address its inefficiencies, drawing attention to the wide range of environmental, economic and social impacts derived from these systems. The evaluation of sustainability represents a challenge as it involves the understanding of different disciplines, actors, and concerns along the food supply chain. Among the different methodologies of evaluation, the Life Cycle Thinking (LCT) approach emerges as a complex and complete holistic assessment method unveiling the environmental, economic and social impacts occurred in each segment of the food supply chain while providing improving scenarios. The scope of this research is to contribute to the development and understanding of LCT approach, and to apply this approach to selected case studies. More specifically, this work was designed to achieve the following aims: 1*) To understand and assess the environmental and cost impact of food consumption and waste in different school canteens typologies,* and 2*) To identify the perception of consumers regarding the sustainability of the chocolate life cycle and compare it with experts' opinion.* The first aim was accomplished by the development and analysis of two case studies, one in public school canteens in Italy and the other in a private school in the US. In each case, different food quantification techniques were explored, including visual assessment, digital photography, weighing, and sorting to quantify food consumption and waste. The environmental and cost impacts were evaluated following the LCT approach. The second aim required the active participation of a range of stakeholders to increase the understanding of the chocolate value-chain. The method combined literature review and consultation with consumers and chocolate value-chain experts. The outcomes allowed to understand what is perceived by the consumers and what is behind chocolate sustainability according to experts. The focus provided an examination of the environmental and socio-economic impacts, the role of labels in informing consumers, and the relevance of the FLW of cocoa and chocolate.

Overall conclusions addressed the major challenges for applying the proposed methodological approaches, the main environmental and cost impacts related to the food supply chain, the role of FLW, and recommendations to transfer research knowledge into policy actions.

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INTRODUCTION

Global food system

Global food production heavily contributes to natural resources overexploitation, accounting for more than 70% of freshwater withdrawal and for about 30% of all greenhouse gases of anthropogenic origin (Angelo et al., 2019; Garnett, 2011; Whitmee et al., 2015). The current food system generates unbalanced effects on food security and health, with more than 820 million people struggling with hunger and 680 million obese individuals (FAO et al. 2018). In the social domain, agricultural workers account for two thirds of the world extreme poverty, in addition to be the most affected by natural catastrophes. The hidden costs of the food system's strain on health and the environment, as well as other economic costs, such as rural welfare or food loss and waste (FLW), amount to $12 trillion (The food and land use coalition, 2019).

The important intensification that has been occurring in the food sector during the past decades is damaging the state of the planet and compromising its productiveness, while insufficiently providing food and nutrition for all (FAO, 2018a). In a 2050 scenario, an intensification of 119% in edible crops production would be needed to feed the expected increase of the world population (Berners-Lee et al., 2018). This substantial growth will be inevitably associated with a rise in the exploitation of natural resources potentially threatening the ability to produce food and accordingly challenging food security (Prosekov and Ivanova, 2018).

On the other hand, agriculture represents a key sector to actively address sustainability. From the climate perspective, it can contribute to climate change mitigation by reducing emissions intensity (improving production efficiency) and avoiding additional loss of the carbon stored in forests and soil (FAO, 2016). It is demonstrated that agricultural productivity also benefits from the development of human and social capital, such as facilitating the provision of training for workers to learn new professional skills, accompanied by an introduction to available technologies to improve production efficiency. The expected farmers' increase in market condition readiness would provide a better socio-economic field of play (OECD-FAO, 2019). These efforts should be simultaneously applied with actions to nudge more sustainable food consumption patterns and reduce FLW.

Targeting sustainable food systems requires a holistic approach aiming at successfully providing food security and nutrition, benefiting the society and creating a positive or neutral impact to nature (FAO, 2018b).

A shift towards more sustainable food systems

The challenge between population growth and natural resource exploitation increases the pressure to a transition from linear to circular food supply chains, including the end of the life cycle, therefore waste management. The circular economy wants to decouple the economy from the consumption and reduce the extraction of new materials while eliminating waste along the supply chain. This paradigm, developed in environmental economics, asks for a self-effective production that encompasses sustainability (Genovese et al., 2017). Although the competition over scarce resource historically represented a major focus for economics (Robbins, 1932) its urgency and the need for this transition to non-linear and less resource intensive production systems increased dramatically only recently due to the clear evidence of the effects on the environment and human communities.

A sustainable food system should be protective and respectful of ecosystems and biodiversity, acceptable from a cultural perspective, fair, affordable, nutritionally appropriate, safe, and healthy (Burlingame and Dernini, 2012). Consequently, the food supply chain should be holistically analysed, identifying and characterizing each segment of the chain, understanding where the loss or waste occurs, and assessing implication in the three areas of sustainability. The undeniable need for baseline information to tackle inefficient routes is fundamental when building sustainable food systems. Moreover, approaching FLW is also essential since the impact of a product grows as the number of operations and their complexity increase (e.g. processing, transportation, packaging or manufacturing). Considering this fact, a product wasted at the end of the supply chain, as it can occur at consumer level, will have a higher impact than those wasted in previous stages.

How can sustainability be measured?

Since sustainability represents a major challenge for current food and production systems, the research for appropriate tools and approaches for its measurement involved a number of scientific disciplines.

Cost-Benefit Analysis (CBA) is a major instrument applied to evaluate sustainability. CBA combines prices flow analysis, environmental consequences (by including externalities), and the social perspective of different projects or policies. It mostly adopts money or welfare as a unit of reference (Hoogmartens et al., 2014). International organizations have also elaborated sustainability tools, such as The Food Agricultural Organization, FAO (2014), with the design of specific guidelines for assessing the impact of food and agriculture operations on the environment and people. Similarly, the Global Reporting Initiative wants to support businesses and governments to understand and communicate their impact on sustainability by providing a set of specific standards (GRI, 2019). The interest of investors on this topic has promoted the creation of dedicated indexes such as The Dow Jones Sustainability Index (DJSI), widely recognized in the stock sphere and considered as a fairly acceptable proxy of sustainability (Chams and García-Blandón, 2019). Also, certification standards, such as Fairtrade or Rain Forest Alliance, propose product information about ethics, environmental or social features of food products (Vecchio and Annunziata, 2015). Within this framework

the methodological approaches most widely adopted are those under the life cycle thinking (LCT) framework including Life Cycle Analysis (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA) and the integration of the three into the Life Cycle Sustainability Assessment (LCSA). These techniques allow individuals and businesses to assess the impact of their decisions and production methods along with different aspects of a system or a value chain (UNEP, 2011).
This research has adopted the LCT approach.

Addressing environmental, economic and social impacts through LCT

LCA is a methodology that considers and analyzes a product over its entire life cycle to quantify its environmental impact. It is standardized by the ISO 14040:2016 which defines the principles and framework where the method should be performed (ISO, 2006, 2002).
Environmental-LCC assesses costs directly covered by one or more actors during the life cycle of a product and can internalize externalities (De Menna et al., 2018; Hunkeler et al., 2008). Although this method is not standardized, it follows the LCA approach to provide an integrated outcome. Results are crucial to engage actors as they utilize the monetization to measure the different costs occurring along the food supply chain.
S-LCA is a methodology that aims at assessing the social impacts of products, with the ultimate goal of improving human well-being. The outcomes support the adoption of well-informed choices. It is designed to provide, together with LCA and LCC, the full outlook of LCSA (UNEP-SETAC, 2009; UNEP, 2011). S-LCA is still in at early stage in its development, due to the limited case studies analyzed associated with the complexity of identifying appropriate and reliable social indicators.

Objectives of this research

The scope of this research is to contribute to the development and understanding of LCT approach, and to apply the LCT approach to selected case studies. Selected case studies aimed to:

1) understand and assess the environmental and cost impact of food consumption and waste in different school canteen typologies:
   - by investigating different food consumption and waste techniques:
     - quarter-waste visual assessment
     - weighting, digital photography, and sorting
   - by performing a life cycle assessment and environmental life cycle costing to assess the environmental and cost impact of a canteen meal.
   - by analyzing different countries.

2) identify the perception of consumers regarding the sustainability of the chocolate life cycle and compare it with experts' opinion by applying different qualitative techniques such as interviews, questionnaires and focus groups.

Thesis structure

The work is structured in three chapters covering three different case studies.

Chapter 1 introduces part of the first goal of the research by offering to the reader a case study performed in Cento, Emilia-Romagna (Italy). The study aimed at assessing the environmental and cost impact of food consumption and wastage in public school canteens. It applied quarter-waste visual assessment techniques to quantify food waste at school, and an integrated life cycle assessment and environmental life cycle cost to reveal the environmental and cost impacts of meals – including the embedded impact of food waste. The largest cost contribution corresponded to meal preparation stages due to the involvement of labor, while in the environmental dimension, the main contribution derived from food procurement leaded by animal-based products. The sensitivity analysis suggested promising improvements which could be reached by modifying the animal-based composition of the diet and the energy sources of meal preparation.

Chapter 2 completes the first goal of the research by exploring the case of a school canteen in Columbia, Missouri (USA). This case evaluated a combination of weighting, photography and sorting techniques to quantify – and characterize – different food flows in a private school canteen. The environmental and cost impact were assessed by performing a LCA and E-LCC. Animal-based products are these with higher environmental impact, while the labor cost is associated with the largest cost impact. The analysis of embedded food waste evidenced the hidden impacts of this food flow. The research ended designing a preliminary assessment intervention matrix containing a set of proposals to improve meal sustainability.

Chapter 3 is conceptualized to strengthen the understanding of a complex food supply chain – cocoa and chocolate – in their environmental, cost, social, and food loss and waste dimensions. This investigation identified the perception of consumers regarding the sustainability of the chocolate life cycle and compared it with experts' opinion, and evidences from literature. Special attention was given to food loss and waste due to their relevance for the sustainability of the chocolate production and consumption system. The study proposes actions to reinforce the perception of sustainability of consumers.

Conclusions addressed the major challenges for applying the proposed methodological approaches, the main environmental and cost impacts related to the food supply chain, the role of FLW, and recommendations to transfer research knowledge into policy actions.

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CHAPTER 1 - Food waste at school. The environmental and cost impact of a canteen meal

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Abstract

The challenge of increasing food demand due to population growth urges all stakeholders to act against food losses and waste, especially in light of their environmental, cost, and social impacts. In developed countries, awareness raising, and prevention are particularly important at the consumption level, where food waste mainly occurs. In this sense, public school canteens represent a unique setting, because of their capacity of conveying food habits, while sustainably managing available resources. This research assessed the environmental and cost impact of food consumption and wastage in public school canteens through a case study in Italy. It combined life cycle assessment, environmental life cycle costing, and quarter-waste visual methods. The functional unit was defined as the average meal provided by the catering service to 3-10 years old students. Primary data on type and amounts of purchased food, transport, and utilities consumption were provided by the catering service, while food waste assessment was performed in selected representative school canteens. Secondary data on background processes were mainly sourced from databases and literature. Food waste at schools represented 20-29% of the prepared meal, depending on students' age and seasonal menu. The global warming potential (GWP) of the average meal was 1.11-1.50 kg CO_2-eq, mostly due to the food production impact. The meal preparation had the largest impact on costs. When considering embedded impacts, food waste was responsible for 14-18% of GWP and 6-11% of the costs. The sensitivity analysis showed promising environmental and cost reductions by introducing changes in the meal composition and preparation.

1.1 Introduction

The possibility to achieve food security by 2050 is highly dependent on sustainable food system implementation. (Conijn et al., 2018). United Nation recognized the relevance of targeting food system with a composite approach by promoting selected interventions directing specific goals for 2030 in the Sustainable Development Goals (SDG) (UN, 2015a). The SDG 12.3 aims to "halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" and recognizes the importance of involving different stakeholders of the food supply chain (FSC). FAO (2011) estimated that one-third of global food production (or 1.3 billion tons) is lost or wasted. These food loss and waste (FLW) are associated with a total carbon footprint of 4.4 Gt CO_2-eq per year (FAO, 2015), due to both its management and FSC embedded impacts resulting in 2.31 trillion euros of societal cost (FAO, 2014b). These figures cannot be neglected in the context of population growth and corresponding needs.

In developed countries, most food waste (FW) occurs at the consumption level (Bio Intelligence Service, 2010; Janssen et al., 2016). In the UK, avoidable FW accounts for about 13,888 million euros and a total of 22 million tonnes CO_2-eq (WRAP, 2018). Consumption FW (household, caterings, and restaurants) strongly depends on social characteristics and situational factors (Sebbane and Costa, 2018).

School canteens, where food is served, consumed and wasted, confer an ideal scenario to study food systems at consumer level. In the last decade they have gained considerable interest by public and scientific audiences. Frequently, they are considered as behavioral labs, a controlled setting to analyze and improve food consumption patterns (Balzaretti et al., 2018; Derqui et al., 2016; Wyse et al., 2017). Students are next-generation consumers, hence influencing their food-related habits could improve the sustainability of future consumption models (Derqui and Fernandez, 2017; Lagorio et al., 2018; Pinto et al., 2018). Schools are often managed by public entities and policy actions could target consumers while enhancing green or sustainable public procurement (Cerutti et al., 2018, 2016). Additionally, depending on the type of food served (animal or vegetal origin), food production efficiency, meal preparation techniques and energy appliances efficiency , school meals can have a significant environmental impact. (Cerutti et al., 2018, 2016; Jungbluth et al., 2016; Mistretta et al., 2019).

Many scholars approached FW within public canteens to test different methods and goals. Some studies examine different methods of accuracy of food and waste quantification tools (Biltoft-Jensen et al., 2018; Hanks et al., 2014). Other studies propose a common methodology to assess FW in public institutions (Boschini et al., 2018; Eriksson et al., 2018), while some researchers quantify FW and its composition (Costello et al., 2015; Eriksson et al., 2017). Quantification has been also carried out to assess the potential risk of losing the nutritional benefits of prepared food (Cordingley et al., 2011; Kowalewska and Kollajtis-Dolowy, 2018) or analyze food acceptance (Tuorila et al., 2016).

Cited research has been published from 2011 onwards, testifying the increasing attention of the academic research on this topic. However, none of these studies provided an estimate of the related environmental and FSC cost effects with the goal of identify hotspots and provide measures to reduce it.

Therefore, this research aimed at assessing the environmental and cost impact of food consumption and wastage in school canteens, adopting a multi-impact approach. A methodological framework combining quarter-visual assessment (Hanks et al., 2014), life cycle assessment (LCA) (ISO, 2006, 2002) and environmental life cycle costing (E-LCC) (De Menna et al., 2018b; Hunkeler et al., 2008) was developed to quantify food intake and waste, and their associated impacts. Results allowed setting the baseline state of food consumption and waste at school, highlighting areas of improvement and laying the ground for the identification and evaluation of targeted measures.

1.2 Methods

Case study description

The present case study focused on the public schools of Cento, a municipality in the Ferrara province in Emilia-Romagna Region, Italy. This municipality has about 35 547 inhabitants (January 2018) (I.Stat, 2018). Data collection was performed during the school year 2017-2018 considering all 11 nursery (3-5 years old) and 7 primary schools (6-10 years old), for a total of 1 236 students. A private company manages the catering service with a 10 years contract with the municipality. The catering service is centralized in a cooking centre owned and located within the municipality. This centre prepares over 233 000 meals per year, for all students from the age range considered in this study. During the year, there are two types of 5-weeks seasonal menus, with different daily composition. The winter menu is offered for 104 days from November to April, while the summer menu is provided for 80 days from September to November and from April to June. These menus are then differentiated by school grade as food mass provided to primary students is 23% larger than for nursery students.

Meals are prepared according to nutritional and quantitative national and local guidelines, under the supervision of a nutritionist. They generally follow the Mediterranean diet and are divided into 5 courses (first, second, side dish, fruit, and bread). On request by the municipality, the standard meal includes an additional 10% of food (mass-based) to deal with potential differences between the planned meals and the real number of students. As Falasconi (2019) suggested the practice of preparing additional food (between 10-15% depending on the Municipality) is commonly extended in Italian schools.

Food waste assessment

This research adopts the FLW definition provided by Östergen et al. (2014) describing it as any food and inedible food parts , removed from the FSC to be recovered or disposed. A distinction between avoidable and unavoidable has been made following WRAP (2009) guidelines. Avoidable FLW refers to that waste flow that would not exist in case the system is properly in terms of farm practices, market and policy decisions, while unavoidable FLW includes materials that are not edible and cannot be easily avoided, such as bones, skins, leaves. The following flows have been considered:

1) **Preparation waste**: FW occurring during meal preparation at the cooking centre. It is composed both of unavoidable and avoidable FW.

2) **Serving waste**: food left in serving trays and not served to students in the canteen. It is considered avoidable FW.

3) **Plate waste**: food left in the plate by students in the canteen. It comprises avoidable FW.

Preparation waste data were provided by the catering service for every ingredient of the menu, as a percentage of purchased food. No FW was reported for frozen products, as they are directly cooked without any preparation. The provided figure was considered accurate for the aim of this research, as the catering staff is constantly trained in measuring food with their tools, such as spoons, with standard and constant volume.

Serving and plate waste were quantified through a FW audit carried out in a nursery and a primary school, representative in terms of number of students, age range and frequency of meals serving. Data collection was performed for two weeks, one per seasonal menu and covered about 25% of total public-school students' population (300 meals per day).

When selecting the method to assess FW, the following considerations were taken. Direct weighting is considered the most accurate method (Derqui et al., 2018a; Engström and Carlsson-Kanyama, 2004; Liz Martins et al., 2014), but it is not frequently applied due to time and financial constraints (Getts et al., 2017). Visual assessment technique has been validated and recognized as a reliable and accurate visual practice compared to others more time-demanding methods (Boschini et al., 2018; Hanks et al., 2014; Liz Martins et al., 2014). This research adopted a modified quarter-waste visual assessment to analyze the amount and composition of plate and serving waste. Quarter-waste visual assessment assigns to every plate assessed a value between 0-25-50-75-100 referring to the percentage of food left in the plate. In this research, two more values, 10-90, were added to identify students who respectively only left a small amount of food (10) or just tried it (90). The analysis of the 10-90 values was aimed at providing more nuanced information and identify how staff and professors 'intervention could stimulate pupils to taste the food. Following Getts et al. (2017)

recommendations, during data gathering the research team randomly rotated between canteen rooms to avoid standard errors for differences between raters.

The supplementary material includes the template utilized to visually assess plate and serving waste. By filling in all plates and trays quantified in the form, it was possible to calculate the percentage of plate waste per dish. That percentage was then allocated to the corresponding mass based on the weighted average meal. For each course, daily plate waste percentage was calculated as the average of the specific percentages weighted by their serving frequency. The daily serving waste percentage was calculated as the share of portions left in the trays over the total. Total daily waste was calculated as the sum of grams occurred at plate waste – calculated by applying the plate waste percentage to the weight served - and serving waste – calculated by applying the serving waste percentage to the weight served -. Weekly averages per each course were then utilized to calculate the embedded environmental impacts and costs.

Several statistical tests were applied to verify the statistical significance of differences in FW distributions between different grades, menu types, and courses (fruit and bread excluded as they were not assessed in both school types). For each distribution, an analysis was performed in a 3-step procedure as follows. Data were initially screened through a plot test to verify the hypothesis of non-normal distributions (Vogel, 1986). Then, a Levene's test was carried out to prove or reject the homoscedasticity hypothesis (Lim and Loh, 1996). In case of homoscedasticity, a Kruskal-Wallis test was adopted since it allows comparing nonparametric populations under such hypothesis (Corder and Foreman, 2009). Similarly, In case of heteroscedastic populations a two-sample Kolmogorov-Smirnov test was adopted to understand if samples had significantly different distributions (Helton et al., 2006).

Life cycle environmental and cost assessment

Goal and scope

The goal of this study was to assess the direct (i.e. from disposal) and embedded (i.e. from the FSC) environmental and cost impacts of food consumed and wasted in the school canteens of Cento. A combined life cycle thinking approach was adopted. The environmental impacts of FW were assessed through LCA, a methodology that observes and analyses a product over its entire life cycle, quantifying its environmental impact (ISO, 2006, 2002). The cost impact of FW was calculated by applying E-LCC, a method assessing costs directly covered by one or more actors during the life cycle of a product, according to Hunkeler et al. (2008) recommendations.

The functional unit (FU) was one average meal provided at the school, per season and school grade. It has certain characteristics of food composition and weight, as defined by the paediatric guidelines and by the Municipality. Due to the differences in mass and composition between the two schools' grades and seasons, this meal was calculated as the average of the four average meals. All impacts, including FW disposal, were first attributed to this FU and then allocated respectively to the meal consumed and FW.

The environmental and cost impacts were calculated and analysed in the phases indicated in figure 1.1, adopting a "cradle to grave" perspective. This figure describes the system boundaries of the study.

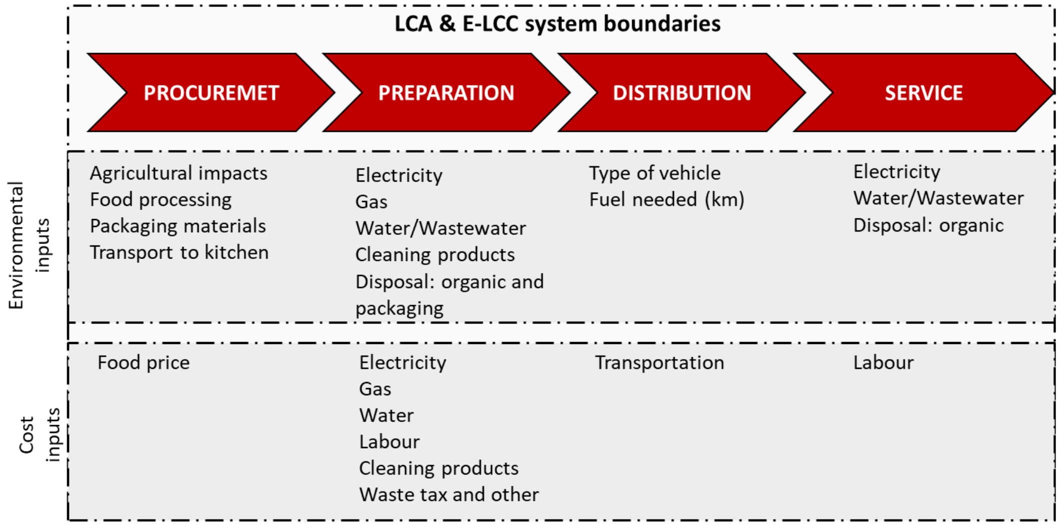


Figure 1.1. System boundaries and phases with related inputs.

Life cycle inventory

Primary data on type and amounts of purchased food, its transport to the cooking centre, inputs for meal production, logistics for the food distribution, human resources and appliances at the service phase were provided by the catering service. Secondary data on background processes were derived from Environmental Product Declarations (EPD), LCA studies, and ecoinvent database version 3 (Wernet et al., 2016).

Procurement phase

This phase includes the activities related to food production, purchasing and transportation from the main wholesalers to the cooking centre. The inputs considered are food production (conventional or organic), packaging, and transportation.

The information regarding the sourced mass of each ingredient has been derived from the calculation of the 4 average menus. For each menu it was considered:

1) **Mass**: the mass for every ingredient provided by the paediatric guidelines in each daily meal, adding the extra 10% of food requested by the Municipality.
2) **Frequency**: Given the rotation schedules of menus and excluding festivities the frequency of each meal was calculated

3) **Students**: the theoretical number of students attending each school during the different days of the week.

Accordingly, the quantification of the average menus and related food purchase was calculated by multiplying the total mass (mass delivered to schools and preparation waste) by the number of students and the frequency by which the ingredient is served in the meal.

The packaging composition of each ingredient has been provided by the catering service company. The materials involved are plastic (PP, PET, LDPE, HDPE, PS), paper, cardboard, mixed (plastic and cardboard), glass, tin, and wood. Packaging quantity has been calculated by allocating each material weight to the ingredient mass.

The amount of km from the wholesaler to the cooking centre and the type of trucks used for transport has been provided by the catering company. This information corresponds to the main wholesaler, and in some cases, it might be underestimated. There is a distinction between refrigerated trucks used for products that need controlled temperature (fresh or frozen) and normal trucks used for products such as rice, pasta, oil, and canned food. The quantity of km travelled for each ingredient and its weight have been multiplied to obtain the total kgkm.

The cost impact of this phase corresponds to the price paid for food purchasing, which was used as a proxy of the life cycle cost up to the cooking centre. The cost of this phase has been provided by the catering service in euros per meal.

Preparation phase

This phase includes all activities needed for storing and preparing meals, including cleaning. Inputs inventoried were organic waste management (preparation waste); packaging disposal management; utilities such as water, gas and electricity derived from the use of appliances, lighting, and space heating; cleaning products for the food, floor, and dishes.

Preparation waste data collection is described in the FW assessment section. Packaging disposal management includes the packaging mass and composition identified in the procurement phase, the transport from the cooking centre to the waste management facilities, and the material recycle. A 100% recyclability has been assumed for every material, considering the nature of the involved packaging and the recycling capacity of the Region. Utilities consumption was derived from related invoices of the catering service, while the cleaning products were quantified according to the cooking centre inventory. It included the chemical composition of each product and the quantity utilized in a year. Each input was allocated to every meal (per school and season) based on the yearly number of meals produced.

Besides these flows, the cost inventory also considers: the labor involved in the cooking centre for food storage, handling, and preparing; waste management taxes; operating costs (car rentals, telephones, PCs, and its maintenance, staff and security); general costs (insurance, contractual charges, financial and coordination charges); investments/depreciation for equipment purchased by the catering service company. All costing information was facilitated by the catering company.

Distribution phase

This phase includes meal transportation by vans from the cooking centre to the schools involving different routes. The first route implies the transportation of the meals in steel trays, inside warm boxes, from the cooking centre to the schools and the empty return. The second route implies the recovery of empty warm boxes, dishes, and trays from the different schools to the cooking centre.

The transport is carried out using light commercial vehicles. The environmental impact was calculated based on the quantity of km and the weight of the load per each route followed. Once calculated, kgkm travelled in each season and school grades were then allocated to each meal.

The overall transportation is outsourced by the catering service company. The cost impact has been disclosed in three categories: labor, fixed cost and variable cost, following the percentage distribution proposed in the EC report (2017). This figure was then allocated to each meal.

Service phase

The service comprises the impact derived from the school canteen activity. From the environmental point of view, it considers the electricity and water used by dishwashers and refrigerators, one of each appliance per school. In addition, it includes the electricity consumed by warm boxes used to guarantee a controlled temperature for warm dishes. These, containing the meals, are transported from the cooking centre to the school canteen where are plugged in until the service. This phase also includes the disposal of organic waste, derived from the plate and service waste. The organic waste data collection was described in the FW assessment section.

From the costing point of view, the catering service company provided the cost of labor for the catering staff. There are approximately 2 workers every 40 students. Inputs such as electricity, space heating, water, and waste disposal taxes have not been considered as they were assumed to represent a limited share of the total costs for schools.

Impact assessment

The impact assessment method measured the following environmental impact categories trough the described indicators:

1) Global warming including global warming potential (GWP) as impact factor (kg CO_2-eq);
2) Photochemical ozone creating considering photochemical ozone creation potential (PQOP) as impact factor (kg C_2H_4-eq);
3) Acidification considering acidification potential (AC) as the impact factor (kg SO_2-eq);
4) Eutrophication considering eutrophication potential (EU) as the impact factor (PO^{-3}_4-eq).

These indicators were selected because they properly represent the impact of studied products and processes in the environment; and are well known in communicating environmental impacts (Schau and Fet, 2008; Strazza et al., 2016).

The main cost indicator was the E-LCC of 1 meal, including all items listed in each phase, expressed in euro (€) paid per meal served. A cost categorization by life cycle phase and type of cost was also used. No analysis of cost distribution among different cost bearers has been carried out since the overall cost is covered by students' parents.

1.3 Results and discussion

Food waste quantification

Preparation waste is higher in courses that include vegetables, as side dish, since their handling requires to manage and dispose leaves, peels and other non-edible parts of food. From the total food purchase, this FW flow represents the 9% of the first dish, 6% of second dish, 15% at side dish, and zero waste in fruit and bread.

The difference between nursery and primary preparation waste is related to the number of dishes prepared, 95 864 meals for nursery students and 137 972 for primary students, as well as to the mass requested in each meal. There is not distention between the percentage of this FW flow as most of the ingredients provided in both schools' types are equal.

About 57% of preparation waste is generated in winter meals while 43% is associated with summer meals, this could be due to the different amount of vegetables needed to prepare seasonal meals. In the winter menu vegetables are mainly used for the preparation of hot soups, while in the summer menu for salads and side dishes.

FW quantification at service phase is disclosed in table 1.1. It is relevant to note that there is no difference between seasonal meals, as differences are due to the number of meals served in each season: 104 in the winter and 80 in the summer.

Table 1.1 . Food waste quantification per course and school type.

	Nur winter	Nur summer	Prim winter	Prim summer
First (%)	8 ± 4	6 ± 5	29 ± 16	22 ± 9
Second (%)	26 ± 14	26 ± 10	27 ± 10	28 ± 15
Side (%)	58 ± 6	40 ± 10	74 ± 13	39 ± 4
Fruit (%)	36 ± 25	24 ± 15	37 ± 9	28 ± 8
Bread (%)	12 ± 11	5 ± 6	0	0
Total (g)	167 ± 132	126 ± 26	154 ± 133	113 ± 91
Per school type (g)	149 ± 86		136 ± 114	

At service stage, FW accounts for about 149g for nursery students and 136g for primary school students (20-29% of meal served). These figures are aligned, although slightly higher, than other studies targeting the same age groups and similar contexts, as plate waste is related to other factors such as meal appearance, time dedicated to eat, and hour of the day when the meal is served (Niaki et al., 2017). Eriksson et al. (2017) quantified 75g of FW in Swedish school canteens, which represents about 23% of meal served. Liu et al. (2016) quantified an average of 130g, about 21% of food served in Beijing (China); and Boschini et al. (2018) suggested that about 22% of food prepared is wasted, in Italian schools.

In terms of mass, first dish is mainly composed of pasta, rice, soup, and vegetables. Second dish includes meat, fish (frozen), potatoes and eggs, while the side dish is primarily made of spinach, potatoes, green beans and carrots. Fruit typology depends on the season, but it is largely composed of oranges, mandarins, apples, pears, peaches and bananas.

Figure 1.2 shows the plate waste and serving waste occurring per dish. Serving waste accounts for about 5% of food prepared, while in this phase plate waste has the largest waste contribution. This result differed with the 64% of serving waste disclosed at Eriksson et al. (2017), which could be due to the buffet style implemented in the Swedish case.

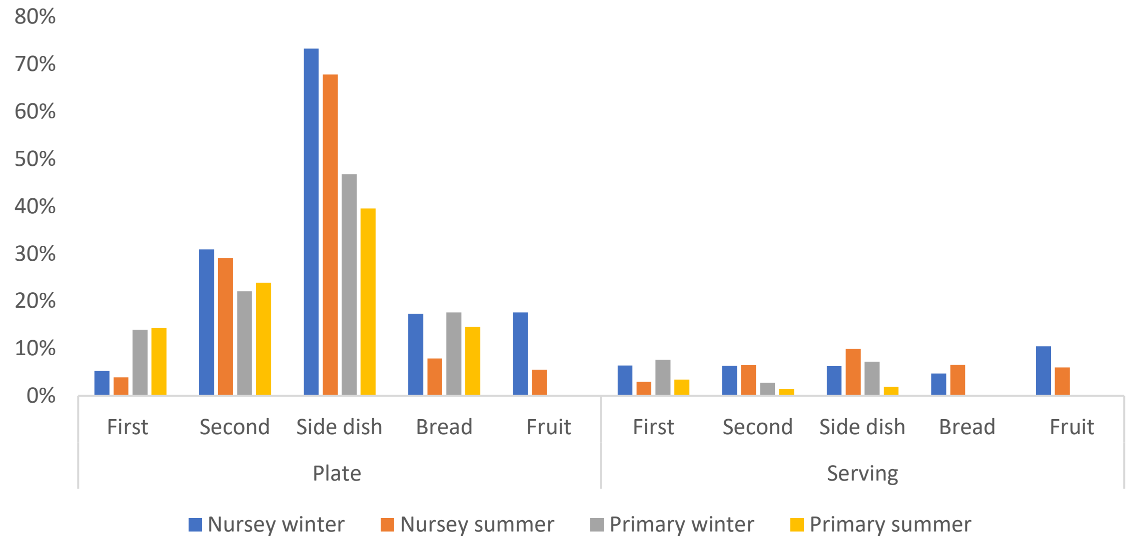


Figure 1.2. Food waste percentage per school grade, season, course and flow at service.

FW distribution between meals is consistent to literature studies (Derqui et al., 2018a; Falasconi et al., 2015; Lagorio et al., 2018) being side dish, or main vegetable dishes the most wasted courses with values between 40-70% of waste. Followed by side dish, the second course contains wasting values 24-30% of the serving course. In primary school, the fruit is not wasted as it is offered to students as a snack before or after lunch. Contrary, nursery students receive ready-to-eat fruit), and when not consumed at lunch it is wasted accounting for 20% of fruit served. Overall, almost 1/3 of food prepared is wasted at the canteen.

These figures are comparable with findings from studies adopting weighting methods (Boschini et al., 2018; Cerutti et al., 2018; Eriksson et al., 2017; Lagorio et al., 2018), confirming that the quarter-waste visual assessment is a reliable and valid methodology for the estimation of FW, as suggested by Getts et al. (2017).

The statistical analysis performed unveiled that meals in each grade, type of school and course type follow a non-normal and a wide heteroscedasticity distribution. The Kolmogorov-Smirnov test confirmed that the distribution between FW in all seasons and grades courses are not equal, as well as the winter-summer FW meals in primary schools and when comparing grades (nursery and primary). This evidence supported the separation of both school grades, courses and season meals to conduct this study. When ANOVA and Kruskal-Wallis tests are conducted to assess the difference of FW between winter and summer in nursery and primary menus, the null hypothesis can be rejected, therefore there is statistical evidence of different distribution between seasonal meals. The wide standard deviation is commonly observed in previously cited studied using weighting techniques.

Food waste impacts

This section analyses the impact of the FU in the assessed indicators focusing on the role of FW.

Meal impacts

The results of the environmental impact associated with the FU have been disclosed in table 1.2 according to school grade and season. Data do not suggest a high variance between seasonality in schools with the same age-range students, instead, there is a difference between primary and nursery school FU.

Table 1.2. Environmental impact category in each school grade and season per functional unit.

	GWP (kg CO_2-eq)	PQO (kg C_2H_4-eq)	AC (kg SO_2-eq)	EU (PO^{-3}_4-eq)
Nursery summer	1.05	4.29×10^{-4}	9.88×10^{-3}	1.12×10^{-2}
Nursery winter	1.16	5.28×10^{-4}	1.09×10^{-2}	1.74×10^{-2}
Primary summer	1.41	6.10×10^{-4}	1.31×10^{-2}	1.81×10^{-2}
Primary winter	1.57	7.05×10^{-4}	1.46×10^{-2}	2.08×10^{-2}
Nur yearly average	1.11	4.85×10^{-4}	1.05×10^{-2}	1.47×10^{-2}
Prim yearly average	1.50	6.63×10^{-4}	1.39×10^{-2}	1.96×10^{-2}
Total schools average	1.31	5.74×10^{-4}	1.22×10^{-2}	1.71×10^{-2}

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

GWP results are slightly below when they are compared with other studies addressing Italian school canteens: Mistretta et al. (2019) reported 1.43 kg CO_2-eq/meal and Cerutti et al. (2018) 1.67 kg CO_2-eq/meal. The first study involved disposable tableware, causing higher impacts compared to the case study of Cento, where tableware is reusable. Storage also represented an hotspot in the study of Mistretta et al. (2019), as there are more frozen products than in Cento where storage period tends to be shorter than a week. This differs from the case of this research, as most of the food is purchased and consumed within the same week. The second study involves large distance between schools, therefore several cooking centres are involved, while in this research a centralized kitchen prepares all meals making it more efficient the preparation phase.

Analyzing other environmental impact categories, PQO has its lower value at packaging disposal subphase, while the higher is related to the food production and utilities consumption at preparation stage. The subphases with higher contribution to the AC are: the food production (about 60% of the total impact), utilities at preparation stage and packaging production. About 95% of the EU impact occurs at food production, followed by the utilities at preparation phase.

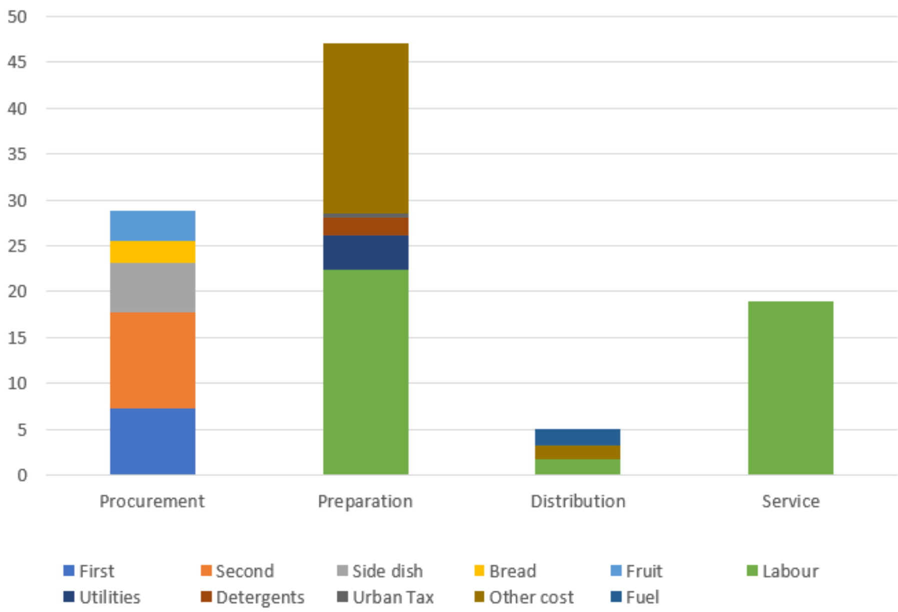
The percentage of environmental distribution is similar in both school grades and seasons. Regarding the GWP average, a 56% is associated to the procurement phase, followed by the preparation phase (32%), the distribution (7%) and the service with a 5% of the total GWP. There is a similar pattern in terms of phase distribution in different school grades. Procurement contains the highest GWP impact embedding about 48% of the total meal impact. This phase considers the impact of ingredients production, packaging and transport from wholesaler to the cooking centre. The influence of the ingredients covers about 85% of the entire phase, followed by the impact of packaging accounting for 14% and transportation for 1%. The main impact is located on animal-based ingredients. In the sensitivity analysis section, this trend is further analyzed. The preparation accounts for 28% of the total GWP meal impact. In this phase utilities such as water consumed and treated, electricity and gas are considered, as well as the organic and non-organic waste disposal and the use of cleaning products. Overall, utilities account for more than 99% of the GWP. When packaging is returnable or characterized by a long-life span (as wood boxes or glass bottles) its environmental impact is reduced.

The distribution phase includes diesel fuel as the environmental input that accounts for 6% of the meal environmental impact. Because food might arrive at the same time in different schools, several vans are involved. Therefore, the value of the distribution is higher than expected, considering that the distance between the cooking centre and the school is about 5 km. Once the meal is delivered, vans return empty to the cooking centre. After lunch, the empty vans go back to the school to collect dishes, trays and warm boxes. The calculation of this phase might be overestimated due to the estimation method utilized.

The canteen phase includes the organic disposal, coming from the two FW flows occurring at the school, as well as water, wastewater and electricity utilized. This phase represents 17% of the total meal impact. Utilities include water and wastewater from the pre-cleaning of dishes (in dishwasher energetic category A) which will be cleaned again in the cooking centre. Utilities contain about 92% of the total impact while FW disposal about 8%.

The distribution of the environmental impacts along the FSC of this research is coherent with other studies analyzing school meals with LCA (Cerutti et al., 2018; Jungbluth et al., 2016; Mistretta et al., 2019).

The costing impact is associated with each analyzed phase as reflected in figure 1.3. The average meal cost paid by parents is 6.25€, regardless of meal or school grade.



Other cost includes general costs, operating costs, depreciation/investments and cooking centre maintenance.

Figure 1.3. Percentage of meal cost associated within each phase and in the whole meal.

Preparation accounts for more than 47% of the total, mostly due to labor cost. It is worth to note that this figure can have far-reaching economic and social implications. In the case of Italy and the catering sector, wage levels and gender balance could be relevant aspects. In the studied country, there is not a recognized minimum salary per work category (ILO, 2019); and concerning gender aspects, in sectors, such as catering service where women make up the majority of the workforce, lower wages are associated compared with those male-dominant sectors (European Parliament, 2017; Santos and Varejão, 2007). These facts suggest that focused on labor cost reduction might be deceptive.

Food waste embedded impacts

The details of the embedded impacts of FW in the service phase per each school and season can be found in table 1.3 and 1.4. They contain the impact category value associated with first, second, side dish, bread, fruit and organic waste management at the service phase. Preparation waste flow is not considered in the embedded impact as this research targets preventable FW at consumer level.

The impact associated to plate and serving waste are calculated by adding the percentage waste of each course, to the impact at the purchase phase (including all subphases) and the subphase packaging disposal located at the preparation. After that, the impact of managing that waste flow has been added to obtain the final value of the embedded FW.

The largest embedded environmental impact associated with the flows is in the nursery winter menu while the lowest is in the primary summer meal for all impact categories. The

GWP embedded in the FW ranks from 15-18%. This difference can be explained by the variation between the amount of food provided and wasted in each school grade.

Table 1.3. Embedded food waste environmental impact and percentage compared to the total environmental meal impact.

	GWP (kg CO_2-eq)	PQO (kg C_2H_4-eq)	AC (kg SO_2-eq)	EU (PO^{-3}_4-eq)
Nur summer	1.66×10^{-1}	1.15×10^{-4}	2.18×10^{-3}	3.56×10^{-3}
As % of meal	15.76	26.68	22.05	31.69
Nur winter	2.14×10^{-1}	1.62×10^{-4}	2.82×10^{-3}	6.05×10^{-3}
As % of meal	18.45	30.69	25.87	34.82
Prim summer	1.94×10^{-1}	1.15×10^{-4}	2.37×10^{-3}	4.18×10^{-3}
As % of meal	13.76	18.87	18.09	23.07
Prim winter	2.44×10^{-1}	1.61×10^{-4}	3.07×10^{-3}	5.09×10^{-3}
As % of meal	15.60	22.89	21.06	24.51

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

From the costing analysis, the embedded impact of FW is located at the purchase phase. The cost shown in table 1.4 corresponds to the FW percentage occurred at the service phase. The costing impact of FW range from 6.48 - 10.51 % of the total meal cost.

Table 1.4. Percentage of costing embedded in plate and serving waste flows.

	Nursery winter	Nursery summer	Primary winter	Primary summer
First	0.86	0.50	1.58	1.30
Second	3.92	3.82	2.65	2.65
Side dish	4.24	4.13	2.86	2.17
Bread	0.53	0.34	0.67	0.36
Fruit	0.95	0.41	0	0
Total meal	10.51	9.20	7.77	6.48

If the Municipality was the stakeholder, organic waste management's taxes and utilities at the service phase could be added.

The role of FW is crucial in the analysis of the meal impact. Reducing current service waste which accounts for 20-29% of the prepared meal, might lead to an overall costing reduction between 6-11% (table 2.4). This figure derives from the direct application of FW percentage (all flows) at procurement phase and 15% of reduction to the following items at preparation phase: labor, electricity, water, cleaning products and urban tax. Other costs located in this phase have been considered fixed, thus less preparation of food will not affect the final cost. At the distribution phase, another 15% reduction has been applied as it is the reduction costing estimation when 29% of the prepared food it is not transported. The service phase has not been modified.

Sensitivity analysis

Inputs with more uncertainty due to the data source and a higher contribution to the results are discussed below from higher to lower contribution to the final environmental impact, considering the GWP impact category.

The first input is frozen fish at the procurement phase. This phase represents 48% of the total environmental impact, while this single product represents 22% of the entire phase. The sensitivity of frozen fish has been tested by analyzing other sources. The value has been obtained from a report (Ziegler, 2002) performing the LCA of frozen cod. The considered figure for the GWP was 6.50 kg CO_2-eq/kg of frozen cod. Most of the studies analyzing fish from an LCA perspective do not consider the frozen phase, or the type of sea fish such as mussel or octopus (Iribarren et al., 2010; Moreira and Feijoo, 2012) assessed is significantly different as the one served at the school canteen. At school, fish sides are mainly composed by plaice, cod and halibut. Other study analyzing cod at the supermarket (not frozen) shows that the environmental impact of cod is about 5.25 kg CO_2-eq/kg of product (Buchspies, Benedikt; Tölle, Sunnie and Jungbluth, 2011). The cooling process consumes energy during its transportation and storage, instead, the FW at the preparation phase is considered zero for frozen products. About 32% of the total carbon footprint of frozen fish is associated to its cooking preparation, this fact has been also highlighted by another study (Vázquez-Rowe et al., 2013). Hence, different scenarios of cooking frozen fish could be analyzed in other studies when combining cooking techniques. In this research fish preparation is mainly cooked in the oven. By modifying the environmental impact of fish according to the discussed sources, the overall environmental impact might change less than 1%, as the frequency of serving is lower than other ingredients.

The second input analysis has been beef at the procurement phase, representing about 15% of the total GWP impact value selected for this product has been obtained from ecoinvent by considering beef production (including bones) in The Netherlands accounting for 21.55 kg CO_2-eq (GWP) per kg of beef. This figure is consistent with other studies, as the case of Bragaglio et al. (2018) analyzing 1kg of live weight of marketed beef cattle in Italy where the GWP value ranks from 17.62-26.30 kg CO_2-eq /kg of beef depending on the feed systems. Buratti et al. (2017) assessing the same FU ranks its value from 18.21-24.62 kg CO_2-eq depending on the production. GWP value is bigger in organic production due to land use change and the quantity of methane emissions derived from enteric fermentation (diet) and manure management. Considering the wider range, from 17.62-26.40 kg CO_2-eq/kg product the GWP would be between 16-23% of the total ingredient subphase. Procurement phase would range from 39-55%, affecting the final impact with an increment of 9% or a reduction of 7%. Beef is commonly served in the first and second dish. Substituting the amount of this product as well as preventing its waste could notably reduce overall environmental emissions; however, nutritional and cultural aspects should also be considered when ingredients are modified.

Electricity consumption in the preparation represents 28% of the meal total environmental impact. This phase is absorbed mainly for electricity consumption (more than 99%). This input has been tested by applying different sources of GWP impact. All appliances are considered under the energy category A, as the catering company invests in improved performance equipment. The environmental impact of electricity was obtained from ecoinvent, with a value of 0.49 kg CO_2-eq./kWh. Considering the electricity mix from renewable energy in the EU, if the GWP varies +/-20% this phase will contribute to the whole meal impact between 26-32%. This evidences that the results resist well modifications in this parameter.

Fuel input at the distribution is the only environmental item assumed. This phase represents 7% of the total environmental impact. The value considered was obtained from ecoinvent with EDP method. It is based on the current vehicle fleet utilized, which is characterized by 4 vehicles sourced with diesel and one with methane. The distance that these vehicles travel could be easily reached by electric vans sourced with renewable energy. Giordano et al. (2018) indicated that replacing diesel vans with electric ones could decrease the greenhouse gases emissions between 35–99%, depending on the route characteristics and the energy mix. Considering a variation between 50% of this input, the final contribution of this phase to the meal will vary from 3-12% as fuel is the only input in this phase. Beyond the fuel emissions, a relevant indicator is the kgkm transported in a year. If this value is decreased by eliminating or reducing the empty transportation and optimizing the routes by minimizing the number of vehicles involved, the distribution phase could reduce its impact by 33%.

In costing terms, labor is the item with a larger impact on the total meal provision. Considering the stability of labor wages, as anticipated before, changes in this item are not likely to happen. Nevertheless, considering the cited 5% of the Italian gender gap, by modifying the labor items +/-5% the final meal cost could vary between 6.12-6.37€. Ingredients procurement is the second largest cost contributor, accounting for about 29% of the meal cost. Literature shows a higher cost of organic vs conventional food of about 30% (Doorn and Verhoef, 2011). Considering that about 50% of the current food provided belongs to organic labels, moving towards 100% organic will increase the final meal price in 0.45€, increasing the final price about 7%. The electricity input is strongly related to environmental impacts as well as highly influenced by price. The current energy market is stirring to more renewable energies in the energy mix, as is indicated by IRENA report (2019), which remarks the Italian growth of renewable capacity by more than 48% in the 2009-2018 period. Moving towards renewable energy, if the cost of electricity would vary between +/-30%, the final meal could change by 0.04€. This cost could be lower if carbon taxes are implemented.

When analyzing the FW flow, the role of the 10% extra supplied by the catering service is relevant in the FW quantification. and to do not interrupt the food service in case a tray is partially damage due to transportation or other adversities. This food flow could be targeted with that extra food composed by long-shelf life and versatile products, which could be stored in school fridges. Catering Staff could manage that food during the week ensuring it is consumed within its life span. These food products should be carefully chosen to keep the same (or lower) environmental and costing impacts as the current scenario.

If a 10% mass reduction is applied at preparation phase, keeping constant the impacts related to cleaning products, utilities (at kitchen and school level) and logistic phase, the overall GWP would decrease between 5.39-5.68%; while the costing impact would be reduced by 4.95%.

Considering FW at plate level a sensitive input, a simulation of +/-20% has been applied to test the final score. The simulation revealed that the GWP would vary between 0.26-0.32%, while the cost would keep equal as the responsible of this cost item at service phase (urban waste tax) would be the school and not the parents. According to these figures, plate waste does not strongly affect the final environmental and costing score.

1.4 Conclusions

This study aimed to assess the environmental and costing impact of the food consumption and wastage in a public school canteen, applying life cycle assessment, environmental life cycle costing, and quarter-waste visual assessment. The research covered every phase of the service, from ingredient procurement to waste management, and identified the related environmental, costing, and food waste impacts. Most of the environmental impacts of canteen meals derive from the presence of animal-based food categories and the use of energy for food preparation. The innovative integration of a life cycle costing highlighted the crucial role of labor needed in the meal preparation. Up to 1/3 of the prepared meal was wasted in the canteens, especially vegetables. The analysis of the embedded impacts and costs of the specific food waste categories emphasized how food waste might represent the indicator of a sub-optimal situation in terms of sustainability and nutrition. The integration of different analytical tools provided the foundations for the design and evaluation of tailored improvement options for public canteens of different grades. The inclusion of food waste represents a novelty as no previous studies specifically focused on its consequences on the environmental and cost impact of a school meal. The sensitivity analysis showed promising environmental and cost reductions achievable by introducing modifications in meal composition and preparation.

Further studies might explore in-depth policy frameworks to boost sustainable diets promoting a better balance between environmental, nutrition and costing variables and considering interventions targeting food waste prevention and reduction.

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CHAPTER 2 - Eating away sustainability. Food consumption and waste patterns in a US school canteen

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Abstract

Sustainable food production and consumption imply the perfect understanding and coordination of the whole food supply chain. In pursuit of this concept, food waste is increasing perceived as a failure in the system. Within school canteens high levels of food waste are generated while 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 aims at assessing the impacts of food consumption and wastage, including the nutritional characteristics in a school canteen, through a case study 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 different canteen users (students and faculty). 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% of the food served as meals, accounting for 10-35% of nutrients. The highest environmental contribution occurred at the food procurement stage, while the lowest occurred at food preparation. The largest costs are associated to food preparation activities and food purchase. 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.

2.1 Introduction

Global food production, including agriculture, forestry and land use activities, causes up to 37% of all greenhouse gases of anthropogenic origin (Angelo et al., 2019; Garnett, 2011). An important part of the emissions can be attributed to food loss and waste (FLW) which involves 8-10% of the total CO2eq of agro-industrial activities and accounts for about USD 1 trillion each year (Angelo et al., 2019; FAO, 2014). In developed countries, more than 50% of food waste (FW) occurs at the household level (Janssen et al., 2016; Vittuari et al., 2019). The Food Agricultural Organization (FAO) (2011) pointed out that between 95-115 kg food is wasted per year/capita in Europe and North America. Consequently, the concept of sustainable food production and diet goes from all stages, until consumption or disposal; and should encompass 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 (Buzby and Guthrie, 2002; 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 school level must usually meet nutritional requirements for a healthy development. In United States of America (US), about 1,249 calories per capita per day are wasted in the uneaten food, while the 26% of calories provided are supposed to be gotten at school lunch (USDA, 2014).

In the US, the second-largest GHG emitters in the World (WRI, 2017), no study targeted food efficiency (including waste) from an environmental, cost and nutritional perspective, where guaranteeing the provision of a sustainable diet is at the core of several national policies (USDA, 2019a). Therefore, it is a relevant setting considering that plate waste represents in this country a direct economic of over USD 600 million (Buzby and Guthrie, 2002).

While in the European Union (EU), the study of Garcia-Herrero et al. (2019) explored the environmental and costing impacts of canteen meals in Italy, no study has been applied an integrated methodology to asses sustainability with a nutritional perspective in US.

This research presents an assessment of the environmental and cost impact of food provided and wasted in a US school canteen, while quantifying the amount of food served, consumed and waste, and its nutritional characteristics related to four school canteen user types: elementary school, middle school and high school students, and faculty. A food waste audit was carried out combining direct weighting and digital photography (Hanks et al., 2014; Liz

Martins et al., 2014) to quantify the mass and identify specific types of foods waste. Life cycle assessment (LCA) (ISO, 2006, 2002) and environmental life cycle costing (E-LCC) (De Menna et al., 2018; Hunkeler et al., 2008) 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, 2019b). Results allowed the building of the baseline situation of food consumption and waste at school, highlighting areas to target the diet, from its sourcing to its consumption-

2.2 Materials and methods

Case study description

The present case study focused on the Columbia Independent School (CIS), a private school located in Columbia, Missouri, US. The role school lunch programs is specifically relevant in rural states, such as Missouri, where they could be identified as facilitators to healthy eating, nutrition education and family preferences (McDonald et al., 2018). This State has increased the obesity range between adults, reaching in 32.5% in 2017, while childhood obesity ranges from 13-16% depending on age (Robert Wood Johnson Foundation, 2017). The school was selected based on its interest to improve the sustainability performance - in 2017 the school conducted an internal waste audit, exposing high levels of waste - and because of CIS covers a wide age-range: 4-18 years old. Additionally, in this city, other FW studies were developed in the past (Costello et al., 2017, 2015), involving an experienced team in the execution of this research.

The school canteen is shared by all students and faculty in different turns. The meal is prepared by an external catering service at the school kitchen. The lunch school plan follows the patterns recommended by USDA on food composition and quantity (USDA, 2019c). The pattern recommends a maximum and minimum of nutritional serving, but it is missing the maximum amount of food items served per week (USDA, 2015). The school kitchen prepares about 370 meals/day for 170 days in the academic year 2018-19.

Meals do not follow any seasonal rotation, except for typical dishes prepared for specific festivities (such as Thanksgiving). Table 2.1 shows an example of a weekly meal, which is served in a tray.

Table 2.1. Example of a weekly meal provided in the school canteen.

	Monday	Tuesday	Wednesday	Thursday	Friday
Choose 1 option	Hamburger	Sausage	Meatball sub	Fish sandwich[1]	Pizza party!
	Hot dogs	Bacon	Chicken nuggets	Cheese Quesadilla	Cheese pizza
	Veggie hot dogs	Veggie sausage	Veggie nuggets		Pepperoni pizza
	Cold meal: Peanut butter & jelly or deli sandwich offered as an entrée alternative every day				
One portion of each	French fries	Scrambled eggs	Onion rights	Potato wedges	Caesar salad
	Baked beans	Biscuit	Peas and carrots	Green beans	Cheesy garlic sticks
	Pineapple	Fruit cocktail	Peaches	Mandarin/oranges	Dessert day

Free choice: Salad bar, fresh fruit, sliced bread & butter, milk & juice offered daily.

[1]*Products containing fish are served on average twice a month.*

The amount of served food depends on the users' age, 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 users, except for elementary school, have access to one hot meal, side dish and free choice of any product described at the bottom of the meal table. Elementary school students must select every morning whether they prefer a cold or hot meal for lunch.

This case study does not aim to be representative of school meals in US, but it could be utilized as milestone in school services, as it follows the US pattern for school lunch and type of food service (in trays).

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 detailed in the Supplementary Materials (SSMM) were used for the environmental impacts of food production, packaging, transportation, utilities, and waste management processes. Nutritional profiles were estimated by using the USDA Research service 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 tried to cover those most representative and included in the Lunch patterns (USDA, 2019c) energy (kcal), proteins (g), carbohydrates (g), total sugars (g), sodium (mg) and saturated fats (g).

Mass flow quantification

This study divided food mass into eight flows as figure 2.1 shows.

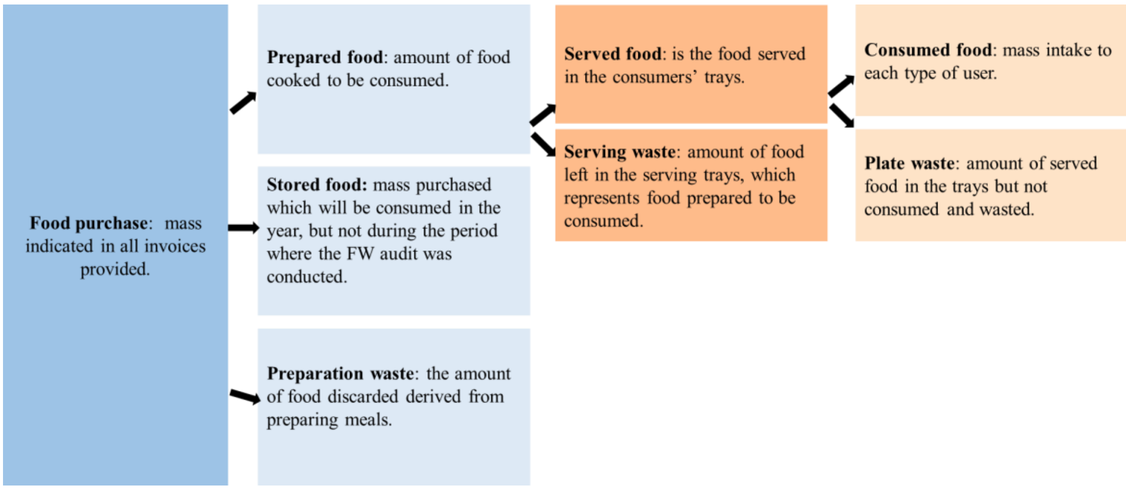

Figure 2.1. Food mass flows considered in this study.

Note that the size of the boxes does not represent food quantity; see Figure 2.3.

Food quantification was calculated by a food waste audit for seven non-consecutive days during November and December 2018, preceded by a test day to understand the canteen functioning and adjust the data collection method. Days were selected to cover the different meal possibilities 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). It consists of weighing meals provided within the canteen to quantify the mass flow. The visual assessment included digital photography to capture the images of food served and plate waste. It helped to understand the tray composition and portion size of all served meals. This technique has been applied in crowded canteens as it represents a valid method to assess food intake (Marcano-Olivier et al., 2019; Winzer et al., 2018). The sorting analysis was performed in two stages. A pre-sorting was first completed immediately after lunch to group same food elements such as cold meal or cocktail fruit to avoid mixing or adherences between them. The second and detailed sorting was conducted at the end of the school day, where the team with the support of high school students classified the food into thirteen categories. Food categories included beef, pork, poultry, wheat, sugar, dairy-solid, dairy-liquid, fish, vegetables, egg, oils, fruit and miscellaneous.

The FW audit started with placing a small card with a number and specific color on each users' tray. The number was randomly assigned while the color represented one of the four types of user. Once the student or faculty had the tray with the meal ready, a picture of the tray on a scale was taken as they left the serving line to sit down in the canteen. The pictures were taken by using 2 tablet devices supported with a tripod along the food serving line, assuring that the weight shown on the scale, the tray number, and food composition were comprehensible in the picture. An example of tray weighing, and image-capture is shown in figure 2.2 When the users finished their meal, a similar photo was taken. As the trays were returned to kitchen staff, the waste audit team sorted the food remaining on the trays by type (first sorting time), into containers for further food-specific weighing if needed (second sorting time). Tray and other food containers were weighed separately to be subtracted from the tray weight reflected in the picture. Preparation (mostly inedible peelings of fruits and vegetables) and serving waste were provided in buckets and food containers by kitchen staff and weighed each day by the waste audit team.

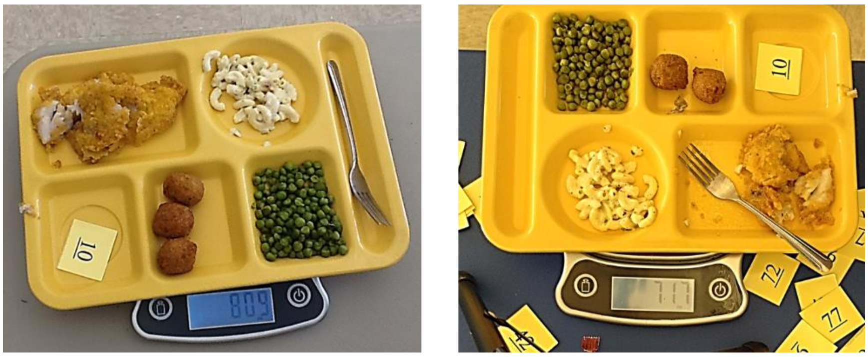

Figure 2.2. Example of pictures taken during the FW audit.

These activities provided the amount of food served, consumed, and wasted at the canteen. The weighing and sorting of the buckets provided by the catering service showed the amount of preparation and serving waste, while the purchased food was also provided by kitchen staff with their food invoices. Prepared food was calculated as the sum of served food and serving waste, while storage food corresponds to the subtraction of food purchased and preparation waste. Hence, there are three FW flows: 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, more related with how the catering staff estimate servings demanded, overpreparation 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 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 a 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), a method assessing the costs incurred during the life cycle of a product, which is directly assumed by one or more actors in the entire product life cycle. E-LCC followed Hunkeler (2008) recommendations. The direct environmental and cost impact of the functional unit (FU) and the embedded impact of FW were quantified through a combined life cycle thinking methodology. E-LCC grounds on LCA phases, and both 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 the users addressed, with the goal of supplying the lunch. In this case, elementary, middle, high students, and faculty. All impacts, including FW disposal, were first attributed to this FU and then allocated respectively to the meal consumed and all FW flows.

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-34) (Heijungs, 1992). The cost impact applied was USD/meal served. It embodies the theoretical cost per user per meal, covered by the parents within the school fee. SSMM provides additional details about mass quantification and cost inputs.

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).

2.3 Results and discussion

This section is divided into three parts: the first part begins with the FW quantification and nutritional characteristics per user type; the second part addresses the meal impacts in detail, through a LCA and E-LCC, including the embedded FW impacts; the last section tested the results by performing a sensitivity analysis.

Food waste quantification and nutritional characteristics

Figure 2.3 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.

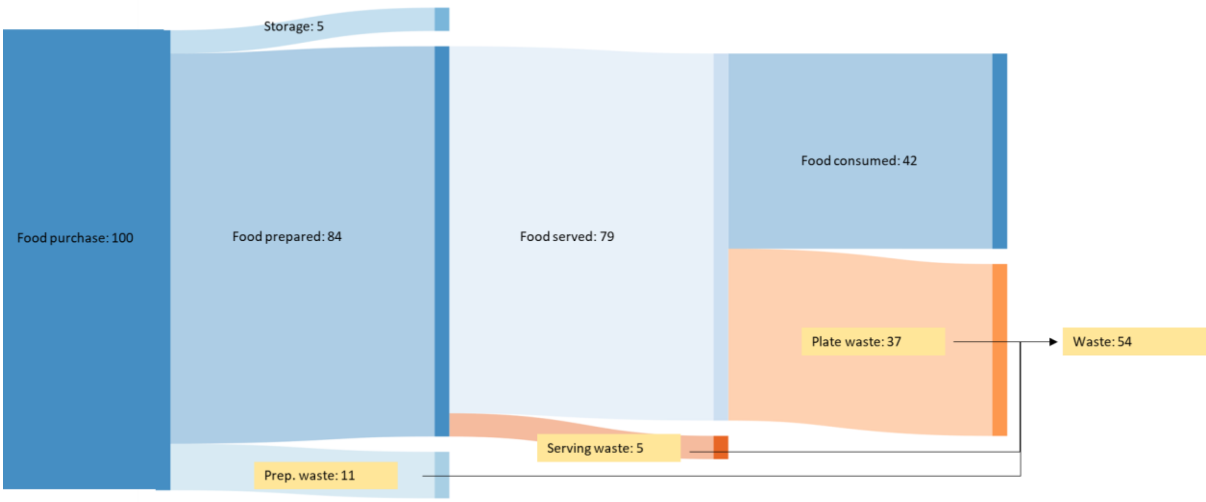

Figure 2.3. Percentage of mass flow at the canteen during the research.

Considering 100% the food purchased, 5% is stored and consumed in the next months. This percentage was calculated through comparison of purchased items and monthly meals. This flow is made of food products with long shelf lives that will be consumed later.

The amount of preparation waste amounts to 11% of the food purchased. The figure is slightly lower compared to other studies assessing canteens (Betz et al., 2015; Fieschi and Pretato, 2017) as it is mainly processed or highly processed 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 84% of the purchased food is prepared to be consumed. It was not assumed any weight change during cooking as many items are highly processed and the weight might not vary. Although this fact is a limitation addressed in the sensitivity analysis, should be considered in further research. This figure has been obtained after the analysis of the FW audit, where all trays were weighed. It represents extra food prepared for expected users and some food choices which have not been selected. The buffet option inevitably involves more FW in this stage, as other studies also found (Eriksson et al., 2017; Silvennoinen et al., 2015).

There are differences between the amount of food served between users as well as the amount per food category. For example, more vegetables are identified in faculties' trays (as they choose to consume more by taking food from the salad bar) than in those trays from elementary school students. The percentages were designed according to the food purchase invoices and, adjusting 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 getting to eat a variety of food to hit nutritional needs and food waste. Table 2.2 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. Plate waste represents approximately 37% of the total food purchased, equivalent to 47% of the total food prepared.

Table 2.2. 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. As the data does not follow a normal distribution, a non-parametrical test was conducted. The Kruskal-Wallis test was performed using Real Statistics on this FW flow. The analysis demonstrated 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. Similar results were found in the food waste assessment performed at University of Missouri dinning campus (Costello et al., 2015)

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 China about 21% (Liu et al., 2016); 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. 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 wastes about 43% of these categories. Understanding the extent to which fruit and vegetable, the highly wasted, 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 less wasted categories (between 0-2%), while oil was not assessed because of the complexity of weighing it to get accurate data. Healthy food is more likely to be consumed in elementary when environmental factors such as noise, crowding and time to eat is managed (Gross et al., 2019). Another data collection technique, aggregate plate assessment, provides a reasonable assessment of food waste quantification, but it would not allow to understand specific food consumption behavior like the combination of techniques utilized in this research to perform the LCA (Chapman et al., 2019). Other techniques, such as quarter-waste visual assessment, a softer data gathering technique (Getts et al., 2017), together with LCA have been applied in Italian school canteens (García-Herrero et al., 2019). This was possible because in the Italian case the meal recipe (specific mass and ingredients) was provided by the catering service, while the meal serving structure (organized by providing a first, second, side dish and fruit) allowed the application of quarter-waste visual assessment to calculate food waste per dish.

Table 2.3 shows the outcomes of the nutritional balance of food categories per each canteen user. Faculty received the higher amount of all nutritional categories evaluated, except sugar, which was served in larger amount to elementary. On the consumption side, faculty consumed the higher quantity of all six nutritional categories, while elementary the lower quantity with except of sugars, which are lower consumed by middle.

Table 2.3. Nutritional balance of food served and plate waste per meal.

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

The amount of kcal served corresponds to the indicated 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, 2019c). 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 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. Sodium levels respected the recommendations established until July 2024, while being larger in all canteen users when considered recommendations from 2024 onwards (between 935 and 1080 mg at maximum).

The type of 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 regarding the minimum (as there is not a maximum contemplated) of meat or meat substitute a day, vegetables, legumes, grains and fruit. The ratio between nutrients provided and wasted is higher than other studies in US, where also food nutrients associated to 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 2.4.

Table 2.4. 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 CO2 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 CIS these aspects were not present. Other studies assessing other environmental impact categories in meals have not been found. It should be noted that mentioned studies included high food preparation at school kitchen level, while this research should be compared with other schools with similar levels of ready-to-eat meal products.

On average, about 85.10% of the overall impact is associated to procurement activities, 13.14% to preparation, and 1.76% to service stage. Table 2.5 shows the percentages of the average meal in each stage.

Table 2.5. Percentage of environmental impact category per stage in an average meal.

	GWP (kg CO_2 eq.)	PQO (kg C_2H_4 eq.)	AC (kg SO_2 eq.)	EU (kg PO-34 eq.)
Procurement	81	84	91	90
Preparation	16	15	7	9
Service	3	1	2	1

Procurement phase 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. Instead, when analyzing the AC, the main impact is located under the beef, pork and poultry categories. The difference between the greatest and the lowest food impact is more than 10^3. 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 Tetra pak packaging, 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 any kind of refrigeration. This research has considered that all transportation has been performed with refrigerated trucks, to keep both fresh and frozen products safe.

Approximately 2/3 of the purchased food was highly processed. This fact could cause a higher environmental impact in the procurement phase than in the preparation phase, as ready-to-eat meals do not need extensive, or sometimes any, cooking process. Instead, when home-prepared and ready-to-eat meals are compared, different results arise. 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 greater environmental contribution derives from agricultural stages, which are common to both product types. The additional manufacturing stages associated with the ready-to-eat meal, which might represent an additional environmental impact contribution, could be neglected as efficient processing stages are followed, while those efficiency levels are not reached at home-kitchen or small scale.

At the preparation stage, most of the environmental impacts are associated with electricity (due to fridges 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.

An interesting element to be included in the LCA of sustainable diets is nutrition, by using satiety as a central attribute for comparisons of food products (Weidema and Stylianou, 2019). Satiety has been excluded in this research as the main target addressed (students) could disturb the results, as they are into a nutrition learning process, while it could be included in adult diets assessment.

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 2.6 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 2.6. Costing item percentage per stage and final meal cost.

Phase	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
	Floor detergent	0.06
Preparation		
Preparation/	Labor + other costs	56.75
Service	Solid waste	1.60

Another study in Italy 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 was 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 vegetable burgers (highly processed food), and sauces, followed by meat products such as pork (with pork bacon products having the largest price) and poultry, 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 shakes), oil and fruit (mainly canned).

Vázquez et al. (2019) proposed the nutritional-cost footprint to quantifying 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. This research has not tracked this indicator, as it follows a food waste prevention approach.

The embedded impact

The understanding of the FW embedded impact needed a specific analysis of FW composition. Table 2.7 shows the embedded FW impact per user type.

Table 2.7. 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 includes the impact of purchased stage referring to all three FW flows mass, the waste transportation to the waste management facilities, as well as the FW management of mentioned flows as organic and packaging.

The GWP represents between 40-57% of the total meal impact, being larger at elementary school student and lower at faculty, 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 left less food. Regarding the food categories, beef waste is the biggest impact contributor in elementary students, pork in middle school, dairy solid in high students, and dairy liquid in faculty. This outcome is the combination of amount of mass per specific food category impact.

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 propose a program modelling to reach optimized diets, obtaining promising results mixing nutrition, economic or environmental characteristics (Larrea-Gallegos and Vázquez-Rowe, 2020; Westhoek et al., 2014; Wilson et al., 2013). The limitation evidenced of cited studies is the uncertainty of food waste quantification when designing the model constraints, which it 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 proposes 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 in the main three sections covered in this research: FW quantification; environmental impact (considering GWP as the environmental indicator), and cost impact.

First, a scenario with zero waste at plate and serving flows was tested, assuming that all food prepared is consumed. If zero waste occurs at serving stages, 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.

Other scenario could consider do not purchase the food that was wasted, therefore reducing food purchase by 54%. The procurement stage was reduced by 54%, while also preparation stage with 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 food selection 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.

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 5-21kg CO_2eq. By testing the value 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 phase, 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). In the case of the environmental performance, other characteristics besides quantity of waste, and soap composition enter into play, such as the washing temperature applied, quantity of product utilized and the packaging impacts of the product (the type of packaging elaboration and disposal) (Boyano et al., 2016).

Improvement interventions

After analyzing the main limitations to achieve a sustainable diet in the case study, a preliminary assessment allowed to create a set of intervention and evaluation matrix. Table 2.8 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, economic and human resources involvement, and parents and teachers' engagement. This preliminary assessment has the ambition to provide a foundation for future works.

Some barriers identified are canteen users accepting the introduction of healthier options; in this case the effort to reduce the environmental impact could lead to an increase of food waste (Byker et al., 2014), thus parallel actions to avoid this should be integrated. The inclusion of a shorter food supply chain could be done by reducing the distance to the main wholesaler, but it is encouraged to reduce the miles to the origin of food products. This might be a challenge when no local or state-level options are available for widely consumed food products, such as bananas or olive oil. The effect of communication campaigns to reduce FW has been widely recognized in college canteens, while still further research would be needed at grade schools. Next steps could be focused on prioritizing and implementing the interventions proposed.

Table 2.8. 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) Wynes et al. (2018) Ribal et al. (2016) González-García et al. (2018)	**M-H**
Food waste Environmental Cost	Sustainability plan. Develop an plan to integrate all school activities, including the canteen service. The plan addresses social, economic, nutritional, food waste and environmental aspects with key performance indicators, within optimization models.	Larrea-Gallegos and Vázquez-Rowe, (2020) Liz-Martins et al. (2016)	**M-H**
Embedded impact	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); M=medium (yellow); H=high (red)

2.4 Conclusions

Sustainable diet implies the supply of balanced nutrition, provided it is totally consumed. Consequently, food waste should be seriously addressed from both, a nutritional, educational, environmental, and cost perspective. This research aimed at assessing the environmental and cost impacts, as well as the nutritional characterization of meal consumption and wastage at the Columbia Independent School in Columbia, Missouri (US). The novelty of this research relies on the integration of recognized assessment methods, including the concept of embedded impact, into a scenario widely identified in US schools. It 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 be extrapolated to other canteens (even outside the school), countries and optimization models. In this frame FW plays a relevant role, being associated with high environmental and cost impacts (mainly related to meat), and nutritional losses damaging the meal balance. This research also evidences that the flexibility of the National Guidelines in terms of maximum of food items provided, could lead into a nutritional gap when some items are not consumed while others in are consumed in excess.

The limitations of this study derived from the fact that it explores one case study which respects 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 to each food item, thus an estimation was utilized. Additionally, food processing environmental impacts might be improved as it was 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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CHAPTER 3 - Sustainability concerns and practices in the chocolate life cycle: integrating consumers' perceptions and experts' knowledge

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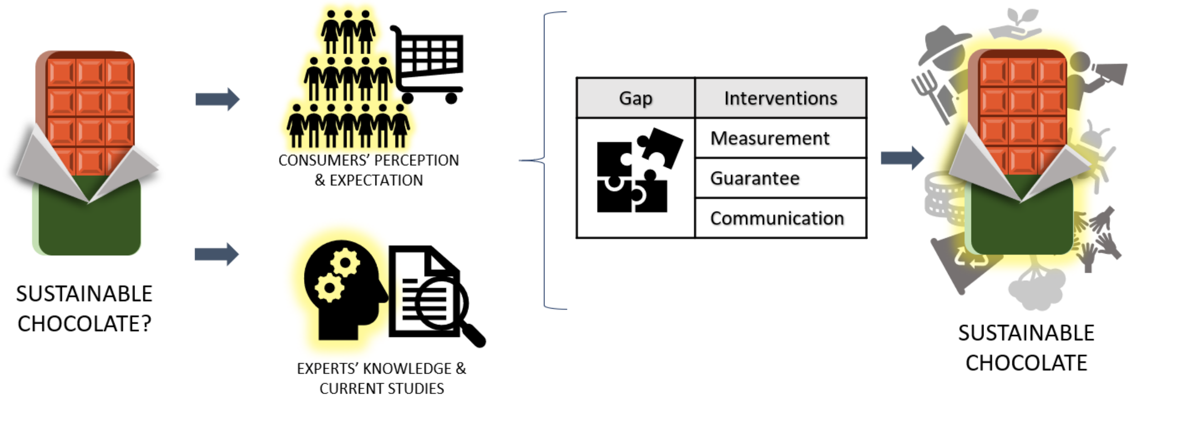
Keywords: *food sustainability; chocolate; consumers' perception; food loss and waste sustainable labelling*

García-Herrero, L., Menna, F. De, Vittuari, M., 2019. Sustainability concerns and practices in the chocolate life cycle: Integrating consumers' perceptions and experts' knowledge. Sustain. Prod. Consum. 20, 117–127. https://doi.org/10.1016/j.spc.2019.06.003

Abstract

A trade-off is faced by products and services' providers: reaching economic profitability while respecting the environment and benefiting the society. A sustainability balance is fundamental to satisfy human needs in a resource-scarce global context. Consumers' behavior plays a key role on sustainability due to its purchase power, but sometimes the absence of information or fully label understanding results into uninformed decisions. A highly processed product widely consumed in developed countries is chocolate, despite the environmental, economic, and social impacts of its production. The aim of this research is to identify the perception of consumers regarding the sustainability of the chocolate life cycle and compare it with experts' opinion, and evidences from current studies. Special attention on food loss and waste has been made due to its relevance in the sustainability sphere. A combination of literature review and consultation to consumers and chocolate value-chain experts evidenced the gap between what is expected by consumers and what is recognized by experts and literature. Lack of fully understanding of labels, missing information about cocoa crops and its connection with deforestation or, the absence of studies dealing with the social, economic and environmental impacts of chocolate life cycle have been identified as some of the gaps. These could be fulfilled by improving the lack of a common assessment method applied to measure sustainability in a comparative way, the dearth of buyers' trust to certifications by enhancing its meaning, and the poverty of communication received and understood about sustainable products by targeting specific consumers' needs.



Graphical abstract

3.1 Introduction

Modern food supply chains are comprised of complex sequences of resource-intensive operations, requiring the employment of significant human, financial, and natural resources, with related social, economic, and environmental implications. The intensity of such impacts induces companies, public authorities, international bodies, and other stakeholders of the agro-food sector to seek innovative solutions for the improvement of working conditions, an optimized use of resources, and the reduction or valorization of losses. This quest for sustainability involves the integration of economic, social, and environmental parameters in the whole supply (Pope et al., 2004), as emphasized also by the United Nations through the adoption of the Sustainable Development Goals (SDGs) (UN, 2015b). Specifically, SDG 12 targets, regard each product at all stages of the food chain with a notable importance on semi-processed and processed products. It remarks the need of responsible consumption and production, promoting resource and energy efficiency, enhancing the role of sustainability production along the life cycle.

This alignment between buyers and policy makers on boosting sustainable products presents a favorable scenario for the sustainable development (Kim et al., 2013; Vecchio and Annunziata, 2015b). Consumers are a particular stakeholder, considering their increasing interest about sustainable products and their bottom up power to move the system toward sustainability (Camargo et al., 2019). Nevertheless, from the consumers' side, there is inconsistence between the intention and behavior when they purchase food products, breaking this ideal scenario (Vermeir and Verbeke, 2006).

Different sustainable consumption indicators show a disparity between what current sustainability assessment methodologies are providing, and if they do or do not fit consumers' needs (Shao, 2016). The deficiency of sustainability-label accessibility, understanding, and standardization could be one of the reasons interrupting the transmission of information to consumers (Annunziata et al., 2019; Rousseau, 2015).

The chocolate value chain

Chocolate is a highly processed food characterized by a composite value chain and a complex system of interconnected operations. Before becoming a bar, cocoa beans undergo a number of post-harvest processes and activities such as shell removal, fermentation, drying, cleaning, roasting, grinding, refining, fat addition, conching, moulding chocolate, and packaging (Beckett, 2009). The largest producers of cocoa; Côte d'Ivoire, Ghana, Nigeria, and Cameroon; are located in the African "cocoa belt", which covers about 70% of the total world production (Wessel and Quist-Wessel, 2015).

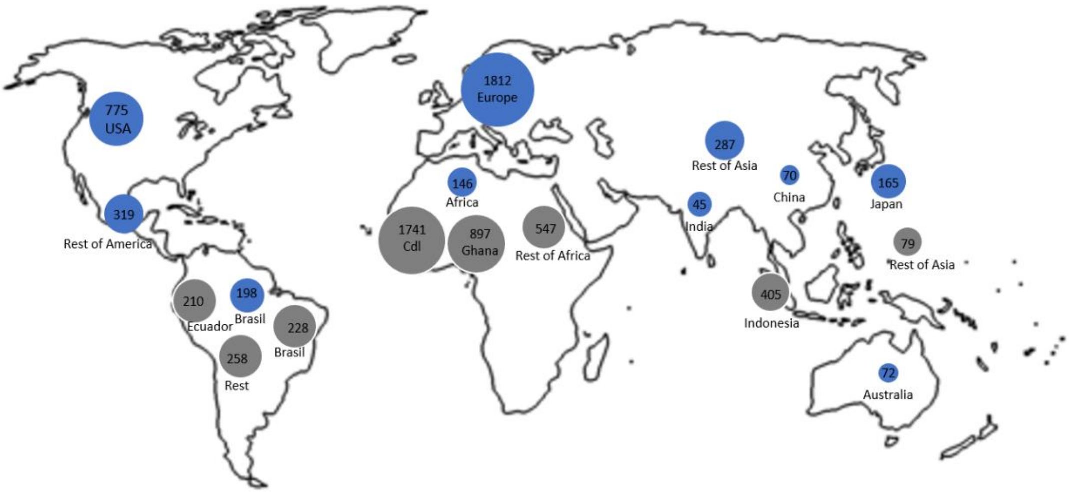


Figure 3.1. Cocoa production (grey) and consumption (blue). Cocoa production or consumption in 1,000 tons, 2013–14.
Author adaptation based on Fountain & Hütz-Adams (2015).

Most cocoa producing countries face serious human rights vulnerability, especially in relation to child labor (Higonnet et al., 2017; Leiter and Harding, 2004), a relatively weak national economy, and a high price volatility (ICCO, 2007; Wessel and Quist-Wessel, 2015).

The cocoa supply chain is geographically extended due to the large distance between raw materials production, processing and distribution of the final product, as well as a vast number of implicated stakeholders affecting cocoa prices. This implies some negative externalities such as the greenhouse emissions of transport and manufacturing activities and the failure to guarantee traceability due to poor governance systems in most of the cocoa producing regions (Saltini et al., 2013).

The future of this product is a challenge, considering the expected growth of the demand of chocolate, estimated to increase by 30% by 2020 (Beg et al., 2017; ICCO, 2017) and the land competition with other activities such as oil crops (Peprah, 2015).

There are studies showing the impacts of cocoa and chocolate on the different sustainability dimensions (Higonnet et al., 2017; Perez Neira, 2016; Recanati et al., 2018; Vesce et al., 2016), but no analysis has attempted to investigate the three sustainability pillars with a systematic approach including the implications related to food losses and waste (FLW). This could be mainly due to the lack of scientific literature focused on performing a social assessment (Petti et al., 2016), combined with the lack of indicators to cover all life cycle length (De Luca et al., 2017).

Several organizations, such as Fair Trade International or Rainforest Alliance, adopt standards designed to tackle poverty by empowering farmers and sustainable agriculture ("Fairtrade International," 2018, "Rainforest Alliance," 2018). Recently, the International Standard

Organization (ISO) launched ISO 34101 series (ISO, 2019), addressing sustainable and traceable cocoa production including economic, social and environmental requirements. ISO 34101 series could adopt in an inclusive and recognized frame the sustainability of cocoa, but does not include chocolate production, thus overlooking relevant part of the life cycle.

The raise of new certifications and standards shows both, the interest for the business sector to certify sustainable cocoa production, and their utility to sell products. Even though, there is still an absence of a complete sustainability chocolate supply chain certification.

In addition, consumers perception towards sustainability is essential to promote sustainable purchase models (Grunert et al., 2014), but so far no study addressed consumers' perception towards this daily consumed product and confronting it with experts and current research knowledge.

The aim of this research is to identify the perceptions and expectations of consumers regarding the sustainability of the chocolate value-chain compared with experts' opinion and evidences from literature. A conjunction of tools based on desk research, a focus group, questionnaires and interviews have been conducted guided by the analysis of cocoa and chocolate throw the environmental, socio-economic, food loss and waste, and label topics. Results aspire to reduce the gap between what is expected about sustainability and what is scientifically proved sustainable, by providing a compendium of interventions.

3.2 Methodology

This study follows a combination of tools based on their suitability to explore the perceptions of the selected stakeholder (Lambert and Loiselle, 2008; Schoonenboom and Johnson, 2017). Figure 3.2 describes the methodological framework.

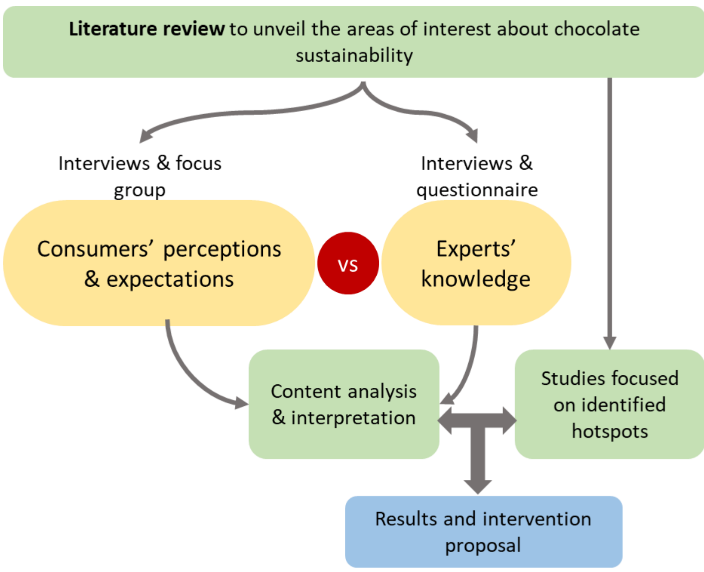


Figure 3.2. Methodological framework.

Literature review

An in-depth literature review was conducted following an iterative approach. Bibliographic databases such as Scopus and Google Scholar, and grey literature – research reports, conference proceedings, and different studies from reliable sources, such as United Nations reports – were consulted.

To set the baseline of the research and identify current gaps in sustainable chocolate, a first literature review was conducted. It allowed to build the interviews, questionnaire and focus group (FG) structure according to main topics on sustainability chocolate. The keywords of searching responded to sustainability consumption, chocolate impacts, and consumers' choice.

The second literature reviewed enriched and contextualized stakeholders' responses. It allowed the construction of the reasoning to fulfill the gap between consumers' expectations and experts' knowledge.

Stakeholders' assessment

This research engaged consumers by conducting face-to-face interviews and by organizing a FG. The combination of interviews and FG addressing consumers specifically, enhances the data richness, recognizes the power of this stakeholder, and its influence on sustainability driver (De Luca et al., 2015; Lambert and Loiselle, 2008).

The literature review conducted at the first stage allowed the identification of hotspots which structured the consultations. The structure followed four pillars: (1) environmental dimension, (2) socio-economic implications, (3) food and chocolate waste (4) the role of labels. Questions distinguished two types of chocolate to the stakeholders were made. The first type, defined as conventional, referred to chocolate produced without any explicit attention to economic development in the country of raw material origin, environmental protection of resources or social implications along the entire supply chain. The second type, defined as sustainable chocolate, refereed to a chocolate produced considering at least one of those dimensions. Organic farming practices were also covered by including organic certifications into the second type of chocolate explained, to understand the value of certifications and labels from this farming practice.

All participants were informed about the purpose of the research and consented to the use of the information facilitated for this study. Interviews' output contains stakeholders' perception and preferences, which could be based on their experience and interactions. Therefore, the responses from this study are treated as perception or expectances; rather than providing an assessment of chocolate sustainability (Camargo et al., 2019).

In pursuance of improving the consumption picture of sustainable chocolate and its genuineness, experts (7) were consulted by interview or by fulfilling a questionnaire following both the same content structure as the consumers but customizing the questions according to the expert profile.

Data gathered through these techniques from both groups of stakeholders were transcribed, coded, and analysed. Identified key statements were coded following a content analysis technique (Elo and Kyngäs, 2008). This tool led to the identification of emerging features that might go unnoticed during a normal transcription (Kondracki et al., 2002).

Consumers' study

In person face-to-face interviews were carried out during two events organized in Italy during Autumn 2017. The first group of interviews was executed at Altrocioccolato, held in Città di Castello (Perugia). The second group was carried out at Cioccoshow, which took place in Bologna. Both events are dedicated to chocolate but Altrocioccolato focuses on sustainable and artisan chocolate while Cioccoshow combines artisanal and non-artisanal chocolate products.

The events selection intended to cover different consumers' profiles. On one hand, profiles with potentially more awareness about the social and environmental issues of chocolate attending Altrocciocolato, and, on the other hand, those with a priori, a less awareness attending the other event. Table 3.1 shows the main characteristics of the events.

Table 3.1. Main characteristics of the chocolate events.

	Altrocioccolato	**Cioccoshow**
First edition	2001	2005
Periodiciy	Annual (Autumn)	Annual (Autumn)
Rationale of the event	It is a cultural event combining fair trade and solidarity projects related to chocolate	It is a recognized event in the country showing diverse stands of chocolate during a weekend
Number of participants	33,000	150,000
Requirements to be a seller	Purchase a minimum of ingredients meeting equo-solidarity requirements Respect sustainability principles	Priority to artisanal chocolate

Authors' elaboration based on ("Altrocioccolato," 2017, "Cioccoshow," 2017; Medium Quattrocolonne, 2017; Schrage and Ewing, 2005).

Respondents were selected randomly among the attendees of the events to target heterogeneous profiles and interviews lasted for about 30 minutes each.

A focus group with 15 participants was organized to ensure a better understanding of the results obtained during consumers' interviews; and to get additional profiles. The FG took place in Bologna with participants between 20 to 35 years of age and with some experience (academic or professional) in the food sector. The FG lasted for about 2 hours.

Experts – artisans, certification bodies and researchers

Seven experts (artisans, researchers and certification bodies) were consulted to discuss similarities and disparities between their experience and consumers' expectations. The experts' selection was based on their detailed knowledge about the chocolate supply chain, including the working conditions of farmers and the environmental pressure of this chain in the producing countries. Due to their expertise, their perspective was crucial for the analysis of the behaviour of various stakeholders as well as the functioning of cocoa and chocolate process. One artisan was interviewed in person while the other experts fulfilled a qualitative semi-structured on-line questionnaire. The data collection tool depended on the stakeholder availability. Elements partially covered by experts, but highlighted by consumers, were analysed through literature, exploring other studies focusing on experts' knowledge or consumers' behaviour (Iweala et al., 2019; Shao et al., 2017).

Despite the relevance of farming systems in the sustainable production, farmers were not directly interviewed due to the technical difficulty of involving them considering the supply chain extension. In order to cope with this limitation, farming perspective was collected from studies specifically targeting farmers, such as Camargo et al. (2019); Fountain & Hütz-Adams (2018), Peprah (2015) or Saltini et al. (2013) among other studies cited along the manuscript.

3.3 Results

Consumers' characterization

Two different consumers' profiles were identified following consumers' behaviour classification observed in other studies addressing similar needs (Carbonell et al., 2008; Jaffee and Howard, 2016).

Group 1 was composed by consumers with more awareness and/or some knowledge about the sustainability impacts of chocolate, while group 2 included those consumers with limited knowledge of and/or interest in the sustainability of chocolate. This classification helped to understand their perception and expectation about this product, as well as their sensibility about food loss and waste. It is relevant to note that Cioccoshow interviewees and FG attendees fell into both group 1 and 2; while all interviewees in Altrocioccolato feel into group 1.

Environmental dimension

A leading aspect identified in the literature review concern with sustainable production and consumption is the effect of the product on the environment.

In order to verify their awareness, consumers were asked to identify the environmental impacts of cocoa and chocolate, and eventually to provide further details. Remarkably, only negative impacts regarding this product were identified by consumers when the environmental dimension was analyzed.

Configuring this section according to the chocolate supply chain, consumers particularly underlined the negative impact of cocoa crops. Specially, monoculture of cocoa, mainly promoted by big firms, was blamed as the cause of deforestation and loss of biodiversity in countries with lax environmental protection legislation. Consumers expects more environmentally friendly crop practices in sustainable chocolate, than in manufacturing phases. Expectation is a key word denoted by consumers and experts, as the chocolate chain is affected by many intermediates in different countries and contexts and controlling could be a complex task.

Literature supports this consumers' concern. Cocoa farming is identified as the main cause of deforestation in producing countries. Throughout 1988-2007, smallholders in the African cocoa belt increased their cultivated area by 3.3% yearly, generating 2.3 million ha of forest loss (Kroeger et al., 2017). Between 2001 and 2004, Ghana lost about 10% of its entire forest cover, one quarter of that deforestation was connected to the chocolate industry (Bellantonio and Hurowitz, 2017; Kroeger et al., 2017). This deforestation is often linked to the illegal crop location in protected areas (Bitty et al., 2015). For example, in Côte d'Ivoire 231 protected areas that have been illegally exploited for growing cocoa and other commodities; and it is recognized by the Ivorian government that 30-40 % of its national production - which accounts for up to 15-20% of the Gross Domestic Product (GDP) - came from protected forest (Human Right Watch, 2016).

Deforestation may cause microclimatic changes, negatively affecting the biodiversity of the forest (Ruf et al., 2015). In addition, the adverse effects of deforestation can be amplified by climate change (Schroth et al., 2016). A study assessing the Swiss shopping basket also confers to the cocoa crops a relevance on the biodiversity (Beretta et al., 2017). Paradoxically, when studies focusing on the environmental assessment of cocoa/chocolate were consulted, biodiversity and deforestation indicators were missing. The exception was the study of Miah et al. (2018), which assessed the ecosystem quality indicator to evaluate biodiversity features. The results concluded that biodiversity seems to be heavily affected by uncontrolled cocoa plantations.

Other environmental impacts of raw material production of the chocolate were not identified by consumers but are crucial according to experts and consulted literature. Both, the production of cocoa and sugar has important impacts on abiotic depletion, eutrophication, and photochemical oxidation, as farming is strongly energy dependent and involves the use of fertilizations and crop protection products (Miah et al., 2018; Perez Neira, 2016; Recanati et al., 2018).

Moving through the supply chain, cocoa transformation into chocolate involves several resources. This stage has been recognized critical by consumers, due to the high demand of energy and water in manufacturing processes.

Experts and studies agreed on the fact that energy in processing during cocoa transformation is relevant. Studies range the global warming potential contribution of energy at this phase ranges between 6- 28% of the total chocolate environmental impact (Miah et al., 2018; Perez Neira, 2016; Recanati et al., 2018). These results, although diverse, are coherent with the different system boundaries and functional units they are dealing with. Consumers' energy concern along this phase is broadly covered by current studies, while there are not many researches about water consumption in the chocolate product, although experts considered important as well.

The connection between transportation and environmental influence has not been recognized by consulted consumers. Instead, it has been identifying as relevant by denoting consumers' interest about the origin country, an aspect that will be further discussed in the labelling section, and that regards more the socio-economic aspects than environmental ones.

Experts did not mention the role of transportation impacts in the environmental concern of chocolate life cycle. There are few publications studying the role of transportation in cocoa/chocolate; and do not consider this phase very relevant from an environmental perspective Some studies show a range the environmental impact of this phase from 1.2% to 9% in their global GWP contribution to the final product (Miah et al., 2018; Recanati et al., 2018); but this value might change from the reality as all studies considered only certain transportation routes excluding others due to confidentiality of data or difficulty to get reliable information.

Analyzing the packaging stage, consumers considered packaging as a relevant feature of chocolate is sustainability. A sign of sustainable chocolate is packaging simplicity, the product is expected to be wrap-up with a single material such as craft paper, and it should be minimal in colors and claims. Packaging is considered essential to protect the product as well as a marketing tool.

The environmental implications of packaging characteristics are specifically mentioned by the experts. They emphasized that during the past 20 years significant progresses have been made on packaging from a food safety perspective but underestimate the related environmental costs. Previously, the packaging was made of paper and aluminum foil 100% recyclables materials, but currently conventional chocolate is often rolled by plastic composites, which are not always easy to recycle. The contribution of this stage to the GWP ranges in the studies consulted between 3-13%, and it is caused by the electricity and heat utilized to extract the packaging raw materials and shaping them (Miah et al., 2018; Recanati et al., 2018).

Consumers, experts and literature agree on the essential role of packaging in sustainability chocolate. Nevertheless, the reasons sustaining this statement are different. Consumers' partially misunderstand the role of packaging, as food contact regulation strong affect the characteristics of this item, it cannot be selected only by marketing purposes, but to accomplish its protection mission ("Food Contact Materials EU regulation," 2018). Although craft paper type of packaging more environmentally friendly than others, such as foil, the organoleptic and safety characteristics should be guaranteed, and craft paper alone cannot accomplish them.

An important feature emerged in the experts' interviews was the absence of comparison environmental evaluation unit when dealing with studies assessing the same product. Even thought, there are methodologies such as life cycle assessment (LCA) allowing the assessment of the environmental impact under a standardize methodology (ISO, 2006, 2002), the flexibility in the application makes difficult the comparison between products and, consequently, this will be translated into the consumers' decision-making when it is communicated.

Socio-economic implications

Consumers linked the socio-economic implication of chocolate with positive development promotion for cocoa farmers' communities. They highlighted their awareness about human risk vulnerability in cocoa producers' countries and how the sustainable chocolate could enhance their living conditions. The positive development was possible thanks to what they call fair wages favored by NGOs behind sustainable chocolate labels. Stakeholders believes that chocolate can reach sustainability when farmers are paid fairly, and programs to improve community's development are promoted by cocoa buyers. Sometimes, the way of recognizing chocolate supporting those communities is by packaging seals, belonging to recognized NGOs promoting fair labor conditions, or by simply purchasing this product in fair trade shops.

Cocoa production is largely based in countries characterized by a low or very low GDP per capita and a smallholder farming system (1-3ha) (ICCO, 2007). The market shows a growing demand (ICCO, 2007; Technoserve, 2015), which leads to erratic prices due to the instable country markets where cocoa is planted (ICCO, 2007; The World Bank, 2017). This supply chain is strongly pyramidal with millions of farmers producing cocoa beans at its bottom, and few traders distributing them at the top (Technoserve, 2015). Hence, the distribution of revenues is largely unfair for farmers, who capture only a limited amount of the final price of a chocolate bar (Technoserve, 2015). Cocoa farmers earn less than one euro per day (Balineau et al., 2016; Bellantonio and Hurowitz, 2017; Fountain and Hütz-Adams, 2018) and they often face human rights violations including child labor (Balineau et al., 2016; The World Bank, 2017).

Experts pointed out the potential role of certification schemes in providing better living conditions to farmers, coherent on what consumers expect. Certified chocolate guarantees a fairer share for farmers, better labor conditions, and more attention to local communities. Examples of better wages are illustrated in Cocoa Barometer 2018 (Fountain and Hütz-Adams, 2018), where salaries perceived by farmers under the fair trade are twice or three times higher than no certificated cocoa. These certifications also provide fixed salaries, helping farmers to obtain financial security and promote investments, as well as get training about sustainable agriculture (Fountain and Hütz-Adams, 2018; International, 2015; "Rainforest Alliance," 2018). Farmers' interviewed in the study of Ortiz et al. (2014) identified how some of them get better price per kg of cocoa by engaging "green labels". This economic stability encourages them to invest more in their field and their productivity increases. The enrolment to these programs involves an improvement in their agricultural techniques, resources management and their income by getting a better price.

A dualism between perceptions is perceived in both consumers and experts. They strongly remark the word expectation and manifested their doubts about what is behind the certifications claims. On one side, certifications could provide the proof of better practices and welfare to farmers and the communities, while on the other side, it is not completed believed that all these improvement programs are implemented.

Additionally, the likely higher final price might generate negative feedbacks at the consumption level, unless accompanied by sustainability-oriented offerings and labelling targeting green consumers. This was confirmed by consumers from group 1 showing awareness about the low income of cocoa farmers and underlined the need for labels ensuring adequate wages and working conditions to farmers. They also believe that more knowledge about the socio-economic performance of companies in producing countries could help consumers in making sustainability choices.

Some were dealing with the social impacts of chocolate in terms of nutrition. These correlate the adequate amount of chocolate consumption to reach a healthy diet and the effects on human feelings before and after chocolate consumption (Crockett et al., 2018; Macht and Dettmer, 2006; Martin et al., 2012). Consumers suggested similar interests, enlightening that nutrition facts are the most consulted label item on the package, especially information on fat, sugars and nutritional composition.

Chocolate evokes different feelings in consumers. Happiness, relaxing, pleasure, calming anxiety were the most shared responses during the interviews. Chemistry offers the explanation; humans have innate taste preferences for sweet, fat and salt because they provide sufficient calories and other essential nutrients for survival motivations (Parker et al., 2006). Most of the women interviewed (65 % of total participants) indicated that they look at the ingredients and calories on the chocolate labels as decision criterion.

Chocolate consumption creates a positive mood (Macht and Dettmer, 2006) and, in particular, when it is eaten mindfully (Meier et al., 2017). Previous research indicate that chocolate consumption causes positive and negative feelings in women. On one hand, it might produce after consumption guiltiness and craving while also activation, tiredness reduction, elevated mood and elicited joy (Fletcher et al., 2007; Macht and Dettmer, 2006).

The superficial analysis of the emotional state addressed within the social relevance of sustainable chocolate has not provided any gap between consumers, experts' knowledge and current studies. Although, according to consulted literature and stakeholders, chocolate has to taste good to reach purchasers.

Food and chocolate waste

Consumers' interviewed consider food waste as a relevant issue. They emphasized social and ethical impacts stressing the controversial relationship between FLW and food security; as well as absence of respect for the labor behind the production.

> *"Some people throw away food while others do not have anything to eat"*

It is well documented that food waste at the consumption stage represents an important expanding hotspot of food waste generation (FAO, 2011; Parfitt et al., 2010). About 24,000 tons of chocolate and sweets are wasted annually in UK, 100% of which is estimated to be avoidable (WRAP, 2009). In economic terms, this waste accounts for approximately 137 million euros per year (WRAP, 2009). Moreover, food waste represents about the 16% of the total environmental impact of the entire food supply chain (Scherhaufer et al., 2018). Chocolate demands high amount of resources when it arrives at consumers. The amount of resources increases when it is not consumed, and it must be treated as waste. Embedded impacts include the management of elements in the chocolate production such as packaging and organic waste.

Chocolate consumption is characterized by a significant seasonality with about the 25% of the total concentrated in religious celebrations, holidays and other special occasions ("Food Business News," 2017).

Starting with the causes of waste, consumers expressed the excess of chocolate gifts during those dates as a reason to waste it. This is linked with sales promotions after those seasonal periods promoted by sellers to avoid food loss. Both, literature and consumers, agreed on that wasting chocolate could occur when consumers' buy more than they can eat because of emotional impulse and discounts (Borgne et al., 2015; WRAP, 2014).

"I get too much chocolate, more than I want to eat. I forget it in the fridge or in the cupboard for long time"

Sales promotions are strongly linked to the seasonal campaign. Experts recognized that they are characterized by a big scene in the supermarkets involving big quantities of chocolate confections located in strategic points of the supermarket.

"Going big, this is the only way to call the attention of consumers. All that remains go to sales. A big performance is needed to sell chocolate"

When targeting directly the awareness about consumers' behaviour about chocolate waste, most of the participants from group 1 recognized that they wasted (few times) chocolate. This result is aligned on what was found in the literature. A study targeting Italian consumers revealed that when consumers have more awareness about food waste and its impacts, they pay more attention on this issue (Falasconi et al., 2019).

In contrast, limited participants from group 2, with less awareness about sustainability impacts of chocolate, recognized wasted chocolate. This could be due to lack of interest of group 2 on the product or their relationship with chocolate: they buy and eat without storing it most of the time; and they do not pay attention on how much they waste. Wasting chocolate was perceived by the consulted consumers as a negative practice in chocolate sustainability. Therefore, consumers recognize their responsibility beyond "buying sustainability products" which is "behaving under sustainability values".

The major reasons of throwing away chocolate expressed by consumers include:

"Chocolate became white and I had to throw it away"

"During holidays, when family and friends exchange chocolate, there is usually an excess of chocolate resulting in potential waste"

"I buy chocolate to calm down, but a quantity smaller than a usual bar's size would probably be enough"

Consumers stressed the presence of ingredients that they do not like as a reason of wasting chocolate. This occurs mainly when chocolate is a gift or when they do not pay attention on ingredients' label when they buy it motivated by eating sweet food instantly.

Packaging damage will be another reason to waste or to not buy chocolate. Consumers claimed that they would not buy a chocolate product with damaged packaging. It prevents moisture transfer, scratching, splitting, and light induced rancidity; being essential in preserving texture, avoiding change of taste and alteration in the appearance and quality of the product (Beckett, 2009). However, it is also a relevant marketing tool for attracting consumers. Packaging distinction is the main strategy applied by some produces/sellers when prices are not the main attraction. Studies about packaging as decision of purchase shows that this aspect is an important marketing tool for food product, considering four elements: size and shape; presence of graphics; product information and technology; time pressure for purchase (Silayoi and Speece, 2004). Purchasers also argued lack of clarity in expiration labels as the reason of wasting chocolate. This aspect will be discussed in the next section.

"Someone told me that that expiration date is not equal to eat before, but I do not know exactly what the difference is. In case of doubt, I prefer to throw the chocolate, it is an affordable product I can easily replace"

Regarding the perception of the impacts of FLW, environmental impacts were pointed to by 70% of interviewees who perceive throwing food as a way of throwing away resources. Resources by consumers meant the product itself, while not mention was made to energy and water needed to produce chocolate, such as manufacturing or transportation. Consumers from group 1 emphasized the importance of food losses, at the beginning of the supply chain covering mainly farmers' role. A limited share of interviewees (16%) recognized the monetary implications related to food waste:

"Throwing food is the same as throwing money"

Consumers' ignored, or did not share any concern about, the losses occurring in early phases of the cocoa production, either at crop or at manufacturing/artisan level. They only recognized those losses belonging directly to them. Instead, at crop and chocolate production stage, including both manufacturing and artisanal products, there are also shortfalls.

The beginning of the supply chain is where the largest share of losses happens, due to the lack technologies and adequate storing facilities ensuring a safe management of cocoa beans (Fountain and Hütz-Adams, 2018; Macht and Dettmer, 2006; Martin et al., 2012; Ozretic-Dosen et al., 2007; Ruf et al., 2015). Significant losses, between 30 and 40% in Côte d'Ivoire and about 25% of in Ghana, have similarly been reported; including as a cause those losses associated with pests, such as the insects Mirids (*Distantiella Theobroma* and *Sahlbergella Singularis*)

(Wessel and Quist-Wessel, 2015). Farming techniques are considered to represent an additional driver of losses by artisanal producers who also pointed out price unpredictability as an additional cause of mismanagement ("Trading Economics," 2018).

At manufacturing stage, the most common practice to reduce waste at production level are chocolate re-work techniques. Re-working chocolate represents a very common procedure in case of damages in the packaging. Nonetheless it includes several limitations including legal constraints, functional deficits, flavor alteration, risk of hygiene deficiency, control of the product (including lot tracking) and presence of allergens (Beckett, 2009). Many certifications assessing sustainability behavior including waste management requirements or recommendations ("Fairtrade International," 2018, "Rainforest Alliance," 2018), but reduction of FLW is not directly targeted. This condition was also confirmed by the experts, which highlights the certification requirements on proper hazardous waste management rather than FLW recommendations but recognizing the growing FLW awareness among different stakeholders.

Literature review has also provided few glances at valorization routes. From a waste perspective, Selim et al. (2014) argues about the use of biofuel derived from chocolate waste oil concluding that it presents acceptable fuel properties. Ranade et al. (1989) studied biomass from chocolate and biscuit waste showing that, excluding paper cuttings, this resources are suitable for anaerobic digestion. The potential of the production of energy from chocolate is confirmed by a other study emphasizing the feasibility of biogas systems (Kamp and Østergård, 2016).

Experts underlined that most of the efforts to avoid food waste are requested to consumers and retailers, not so much to producers. In this sense, a potential driver of change is represented by the SDG 12.3, which aims to develop a coalition of executives from governments, businesses, international organizations, research institutions, and civil society dedicated to halving food waste by 2030 with the initiative Champions 12.3 (Champions 12.3, 2018). This initiative allows the engagement from the all segment of the food chain.

Food waste reduction is necessary to promote sustainability, but at consumer level is difficult to target as it involves a strong intervention: change consumers' behavior (Espinoza-orias and Azapagic, 2017; WRAP, 2009).

All hotspots consideration mentioned in this section suggest that FLW should be properly integrated in the modelling of sustainable products, not only at the end of life, but along the whole supply chain (Corrado et al., 2017; Konstantas et al., 2018; Perez Neira, 2016; Recanati et al., 2018).

The role of labels

Starting from attention to food labels, group 1 was interested on reading labels, mainly information disclosed about nutritional values such as kcal/g, or the product origin; while group 2 was not concerned on labels. These answers provide a combination of insights, first, that labels interest to half of interviews and second, sustainability labels are placed at least in a second place after product composition and nutrition characteristics in terms of comprehension. Consumers' discussed about the problem when reading labels beyond nutritional aspects, while most of them were not able to list even two characteristics of any of the so-called sustainability certifications. This indication could be tackled by improving communication to raise awareness about chocolate sustainability and to explain how certification bodies guarantee good practices. Unfamiliarity of consumers about sustainability labelling applied to food or chocolate, and its need to improve labelling communication and dissemination to be recognized (Reis de Andrade Silva et al., 2017)

Information available on chocolate composition is also indispensable for all stakeholders addressed, but they miss key information as the origin of the ingredients. However, literature discloses that country of origin is a strong driver for consumer decisions (Ozretic-Dosen et al., 2007). The lack of this requested information could be due to the difficulty of transparent traceability by large sale companies and the limited space on the package, as argued by experts. Companies might source cocoa and other ingredients from stock markets, depending on the price, thus mixing beans without distinguishing between countries of origin. It could also be due to the difficulty of setting a common origin as various ingredients such as cocoa beans, cocoa butter or sugar, could come from different countries. It is important to stress the fact that packaging is limited in surface, it must provide a minimum information requested by law, and significant information attracting consumers and origin might be given diminished attention.

When discussing the FLW issue, buyers considered the different shelf life packaging indications in the labels ambiguous, stressing the need for better clarity. The deficiency of clarity in food labels is usually recognized as an important driver for food waste generation (Wilson et al., 2017). This confusion is strongly linked with waste, as in case of doubt (it is expired or not), chocolate is wasted. This product is often affordable and easy to find good in the country of study, consumers prefer waste the chocolate and buy it again.

3.4 Discussion

This section summarizes the different elements risen during the stakeholders' consultation and the review of current studies.

The gaps between consumers' perception, experts' knowledge and literature found in this study, as well as the intervention proposal to reduce them are summarized in table 3.2. Gaps and intervention were both identified by the consumers, or by experts and current studies. Priorities are categorized in very high, high, medium and low, according to their urgency to move the food sector towards sustainability. The criteria selected responded to the urgency shown by the consulted stakeholders their relevance about sustainable chocolate.

Table 3.2. Key gaps identified and intervention proposal according to its type.

Gap	Intervention	Responsible	Type of intervention			Priority
			A	G	C	
Lack of a standardized methodology for sustainability assessment (environmental, social and economic)	Development of a science-based reliable, comparable, and affordable methodology	Researchers	X			VH
	Recognition of the value of this methodology and guarantee its application, quality, and control	Certification bodies Governments Producers		X	X	VH
Insufficient/incomplete awareness about environmental impacts from science to consumers	Further research on specific environmental impacts (biodiversity, deforestation, water use, etc.)	Researchers	X			H
	Further communication about the environmental impact along the food supply chain by relevance and interest to consumers	Governments Producers			X	VH
Lack of trust towards certification standards	Improving the certification knowledge and reputation among consumers	Certification bodies		X	X	VH
	Application of exhaustive food chain controls, including transparency	Certification bodies Supply chain	X	X		VH
Food label illiteracy	Standardized labels	Governments Producers		X		H
	Information and education campaigns	Governments Producers			X	H
Insufficient consumers' knowledge about socio-economic impacts of cocoa production	Facilitate information about the socio-economic impact of cocoa	Governments Certification bodies Producers		X	X	H
Missing information about the origin of raw materials and traceability	Improvement of traceability systems	Producers Certification bodies		X		M
	Further communication about traceability information, such as raw material origin	Producers			X	M
Lack of combined information, nutrition and sustainability	The unification and communication of the relevance of sustainable diet	Governments Producers			X	M
Insufficient responsibility of stakeholders about food loss and waste	Increase the actions and awareness to reduce food loss and waste	Governments Producers			X	M
Lack of information about sustainability packaging	Further scientific evidence on the environmental role of packaging	Researchers	X	X		L
	Lack of recognition of sustainability packaging	Producers			X	L
Lack of evidence on the role of transportation in the supply chain	Additional studies assessing the environmental impact of transportation	Researchers	X			M

A: assessment, G: guarantee, C: communication. Main execution responsible and priority (VH: very high, H: high, M: medium, L: low)-

Thanks to the stakeholders' consultation and the studies analysed it was possible to conclude that, in order to accomplish with SDG 12 and reach sustainable consumption and production the following aspects should be reinforced:

Assessment: Evidenced by the literature review, consumers and confirmed by experts, there is an absence of common measures to assess sustainability in an accurate direction. There are some studies addressing one of the sustainability dimensions but there is not a consensus and application of a formal methodology, therefore a standardization is demanded. This aspect should be urgently solved as it represents the ground, where the next steps are built. A potential framework, able to respond to the sustainability assessment challenge within a life cycle approach, is represented by the Life Cycle Sustainability Assessment (LCSA). It is composed of: Life Cycle Assessment (LCA) assessing environmental impacts (ISO, 2006, 2002), Life Cycle Costing (LCC) calculating costs (De Menna et al., 2018b; Hunkeler et al., 2008), and Social Life Cycle Assessment (S-LCA) examining social consequences (UNEP, 2011) of any specific good or service. LCSA outcomes could support decision-makers in the transitions towards sustainability, by helping them to improve diverse sustainability approaches with a holistic view and a precise detail, and communicate it to provide informed choices (Alexander et al., 2014; De Luca et al., 2015; Kloepffer, 2008; UNEP, 2011). Nevertheless, this methodology faces undeniable challenges to be implemented, such as lack data and methods or how to deal with different stakeholder perspective (such as producer, customer, societal) (Guinée, 2016). Thus, standardization and accuracy are the main characteristics of this intervention.

Guarantee: Consumers did not fully believe what is behind the certifications claims, even experts had doubts. They are skeptical about what the certifications say and what they really do. In order to guarantee good practices, in terms of sustainability, it must be based on a reliable measurement and transparent to maintain a good reputation, and consumers' fidelity (Zhang et al., 2016). It should be easily recognized, from the targeted stakeholders, and simply adoptable, from a time, human and economic resources point of view. Trusted and recognized are the key elements in this intervention.

Communication: The assurance of the certification could be articulated by effective communication. Consumers revealed that satisfying certification requirements is a way to nudge chocolate production toward more sustainable practices. Studies assessing consumers sustainability perception stress the essential role of right communication to favorable behaviors change towards sustainability (Aschemann-Witzel and Peschel, 2019; D'Amato et al., 2019). This communication should be carefully managed as sustainability term induces a range of different networks (Peschel et al., 2019). A consistent representation such as logo or icon demonstrating all sustainability dimensions accomplished with good practice would be useful in decision making rather than the addition of different seals covering specific spheres of sustainability. Therefore, sustainability should be communicated in a clear and concise manner, while provides enough value to be recognized by consumers. Effective and consistent are the key adjectives to describe this intervention.

Conceptualizing the three types of intervention proposals, a triangle shape was built and illustrated in figure 3.3. Influencing the triangle, there are four concepts to be integrated into the typology of the interventions proposed to reach sustainability production and consumption. Sustainability should be transversal, addressing different stakeholders and concerning different topics. It should include holistic aspects, as the integration among disciplines and sustainable dimension. Affordability is key to make the sustainability adoption scalable and fast, as stakeholders should be involved, all should have the tools available to guarantee the sustainability assessment performance and the certification of quality on their process. Consensus term wants to include the necessity of pulling in the same direction, from consumers, experts, producers, policymakers, among other stakeholders who should be engaged. The graph represents the current picture, while sustainability includes a movement towards permanent improvement and coherence of humans living within the social and environmental ecosystem.

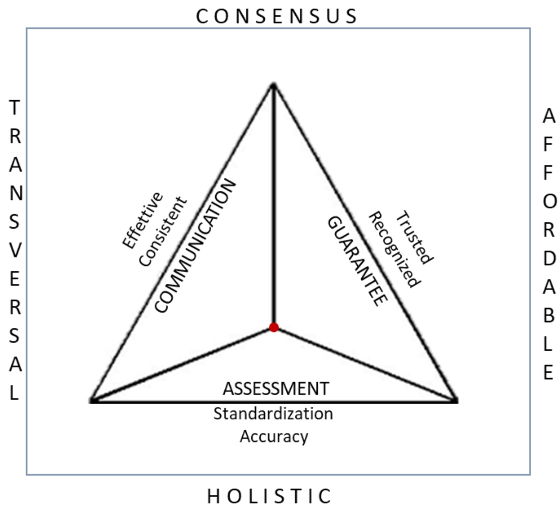


Figure 3.3. Main characteristics to be followed when dealing with sustainable products.

3.5 Conclusions

This research aimed at identifying the perceptions of consumers regarding the sustainability of the chocolate value-chain, crossing the outcomes with experts' opinion and evidences from the literature. This combination of methodological approaches allowed the identification of gaps about chocolate sustainably perception between the consulted stakeholders' and current researches.

Occasionally, consumers' perceptions were based on misunderstood concepts, such as the case of sustainable packaging; while also the research field showed insufficient studies.

The main novelty of this study was the proposal of interventions to reduce the identified gaps between consumers, experts and evidences in regards sustainability chocolate. This research could set a baseline to build sophisticated tools, such as LCSA to assess sustainability in food processed products; the improvement of certain certifications and the aspects where develop specific communication. The combination of social, environmental, and economic implications of a product or service, including FLW, and delivering a holistic assessment represents a critical step to improve stakeholders' decision-making and ensure the circularity of production processes.

The authors recognized some limitations. It has been already mentioned the lack of direct involvement of farmers due to technical constraint to reach them. This issue has been coped with by reinforcing the literature work and selecting experts with broad connection with farmers. From a methodological perspective, the modality of reaching experts – most of them by email due to their availability - might not allowed the gathering of additional information, which has been addressed by literature review.

Further research could start by, on one hand, performing consumer choice experiments considering the gaps emerged in table 3.2. On the other hand, the aspects prioritized in table 3.2 under the responsibility of researchers could be addressed.

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CONCLUSIONS

This research contributes to the debate on sustainable food production and consumption by exploring different sustainability assessment methodologies and emphasizing the role of food loss and waste (FLW) along the food supply chain. The outcomes of this study highlight that the impacts along the food chain are diverse in terms of quantity and source and that simultaneous measures should be taken when considering an integrated approach which balances environmental, cost and social dimensions.

A first aim of this work was ***to understand and assess the environmental and cost impact of food consumption and waste in different school canteen typologies.***

Quarter-waste visual assessment, weighting, digital photography, and sorting techniques were applied to quantify food consumption and waste. The chance to test different primary data collection techniques in diverse geographical contexts - Italy and the US - and school canteen systems - public and private - enriched the scientific work on food consumption and waste. The massive amount of food waste suggested the urgent need to face this challenge, from an ethical, cost, environmental, and nutritional perspective. Although these two case studies were conducted in two places where food waste reduction might not increase the food security of the area, the educational benefits of raising awareness about sustainability in the upcoming consumer generation are undeniable.

The environmental and cost impact of meal consumption and waste were assessed with LCA and E-LCC, in both cases underlining the importance of food procurement selection, as animal-based products involve high environmental impact, together with energy sources. Labor category was the largest cost contribution item to the final meal price, followed by the food procurement. A sustainable diet should find the trade-off between environmental-cost-nutrition and meal intake, a challenge to deal with, considering the canteen users evaluated.

The second aim was ***to identify the perception of consumers regarding the sustainability of the chocolate life cycle and compare it with experts' opinion.***

The methodological design of this chapter allowed to understand the perceptions of consumers and other supply chain actors about chocolate sustainability. Chocolate is a peculiar processed product, characterized by significant impacts and complex operations along its value chain. Though it is widely consumed in developed countries, many aspects about its production are still unknown, from the origin of the cocoa bean and the socio-economic circumstances behind its production, to the resources needed for its transportation and transformation into chocolate. The specific section about FLW unveiled seasonality and price discount campaigns as major drivers for the generation of food waste. Main findings pointed out the several gaps currently existing between consumers' perceptions and real impacts along the chocolate value chain. Thanks to the stakeholders' participation it was possible to identify specific priorities of intervention to reduce this knowledge gap including the development of more comprehensive sustainability assessment tools, reinforce the producers' trust, and more effective communication to consumers.

Methodological developments

The application of LCA and ELCC reveals the hotspots in terms of environmental and cost impacts occurring at each stage of the food chain. The combination of both methods supports a better allocation of resources along the food supply chain, ensure more information about the demand for natural and cost assets, as well as about the main stakeholders involved. The strong need for a common understanding of sustainable food systems tends to fail in integrated complex and extensive methods, as often occurs with a life cycle sustainability assessment due to the broad impact dimension covered. Therefore, the results of LCA and ELCC have been presented separately while sharing the same functional unit and the system boundaries, helping decision-makers to understand why taking specific actions to improve the sustainability performances of food systems. Nevertheless, LCA and ELCC should evolve into better integration once the scientific community masters its application, and decision-makers increase their knowledge about sustainability.

The active involvement of consumers in the chocolate case study recognized the role of stakeholders in identifying hidden bottom aspects strongly related to sustainability. Direct participation did not occur in the school canteen cases, but some students and teacher's decision patterns were recognizable from the eating behavior emerged from the results of food quantification, including both intake and waste.

In the school-canteen cases, the lack of primary data was the main limitation identified, especially in transportation routes or ingredient origin. Also, in the chocolate case, consumers demanded more information about where and who produced their chocolate. This information is often not available considering the commodity treatment of this product, travelling through several hands (physical and virtual), and unknown routes. Deficiency of primary information was also a common limitation suggested from other life cycle thinking studies.

Food consumption and waste were quantified by exploring different techniques: quarter-waste visual assessment, weighting, sorting and digital-photography. The quarter-waste visual assessment allows the identification of the percentage of waste per dish, in a rapid and fairly easy manner. This method offers advantages especially dealing with large food waste assessment when the information about the amount of food served per dish is available (ingredient weight and meal composition) and the number of ingredients is relatively limited. Weighting has the advantage to render the weight of the meal before and after consumption, but it fails to reveal the mass per ingredient served and wasted. This limitation was managed by including a sorting by hand phase. This phase required time and materials, but it could produce interesting outcomes when combined with a didactical approach nudging students' engagement. The digital-photography technique represents a valuable integration to the other approaches as it allows to understand the whole meal composition before and after consumption, while also speeding up the weighting scheme by recording directly in the picture the weight of the trays.

The role of food losses and waste

FLW at school or in the chocolate system has been mainly examined from a quantification approach or as a consequence at the end of the food supply chain, but no study has included an assessment this food flow considering its embedded impacts. FLW represents a market inefficiency, with several externalities associated. Consequently, FLW should be considered as an indicator of sustainability when assessing food supply systems. Obviously the higher are FLW the lower is the sustainability of the system. Results also suggested how this indicator contributed to environmental and cost impacts, although the cost of waste management might need to be adjusted to encourage its reduction as it was not mass-based but calculated as a fixed fee. As the major environmental contribution derives from ingredient production, when this stage becomes more efficient, benefits will be extended also to the upper segments.

Research to policy

LCT raises the knowledge about the complexity food supply chain and provides alternative scenarios to improve the sustainability of food systems. Outcomes might be crucial to take scientific based decisions and to better tailor actions targeting sustainability impacts.

LCA and ELCC represent valuable tools also to identify the most appropriate policy instruments in terms of economic tools, as environmental taxes and tariffs or subsides and rearwards, and voluntary schemes as certifications or deposit systems.

In the school-canteen cases, the alarming amount of food waste might cause harming effects on child nutrition. This study provides information also on the amount of food prepared, served and wasted, as well as on its typology. Considering that information and the fact that unhealthy diets could lead to lack of nutrients, the improvement of this scenario could be achieved by targeting food waste through some policy instruments such as green or sustainable procurements combined with nutritional standards. Moreover, the analysis of the embedded impacts and costs of the specific food waste categories emphasized how food waste might represent the indicator of a sub-optimal situation in terms of sustainability and nutrition.

When focusing on consumers in the chocolate study, there is the perception of an absence of accurate and standardized assessment of the product, lack of label trust due to companies' scandals and understanding of food labels. These evidences could guide policymakers to engage consumers in the transition towards sustainability.

Limitations and further research

LCT approaches require a large amount of data often owned by different stakeholders. Therefore, data collection and management might not represent a limitation, but surely a major challenge. In this research the lack of data regarded mainly the transportation routes of food, from the field to the canteen or to the chocolate processing facility. This deficiency has been mitigated using secondary data sources. Further research based on primary data on food origin and its journey – from the field to the canteen - including costing and environmental footprint inputs could improve the robustness of the work.

The role of FLW could be further explored as current studies evaluating the effectiveness of interventions addressing food loss and waste are still limited. Most of these studies address school canteens and do not provide adequate support to policymakers to design interventions in other domains. Testing interventions in different settings, and expanding these experiments also in school canteens, might represent a crucial target for research.

Also, the analysis of food loss occurring at the beginning of the food supply chain was out of the scope in the school canteen studies. Efforts to include these flows in the sustainability balance could help in prioritizing the selection of certain food products from short supply chains.

The chocolate case was based on experts' opinion from key stakeholders to build on social life cycle thinking but without covering the farming stage of the food supply chain. Further research might continue to contribute to the development of social life cycle assessment and to its integration with participatory approaches that ensure the inclusion of stakeholders' knowledge and perspectives.

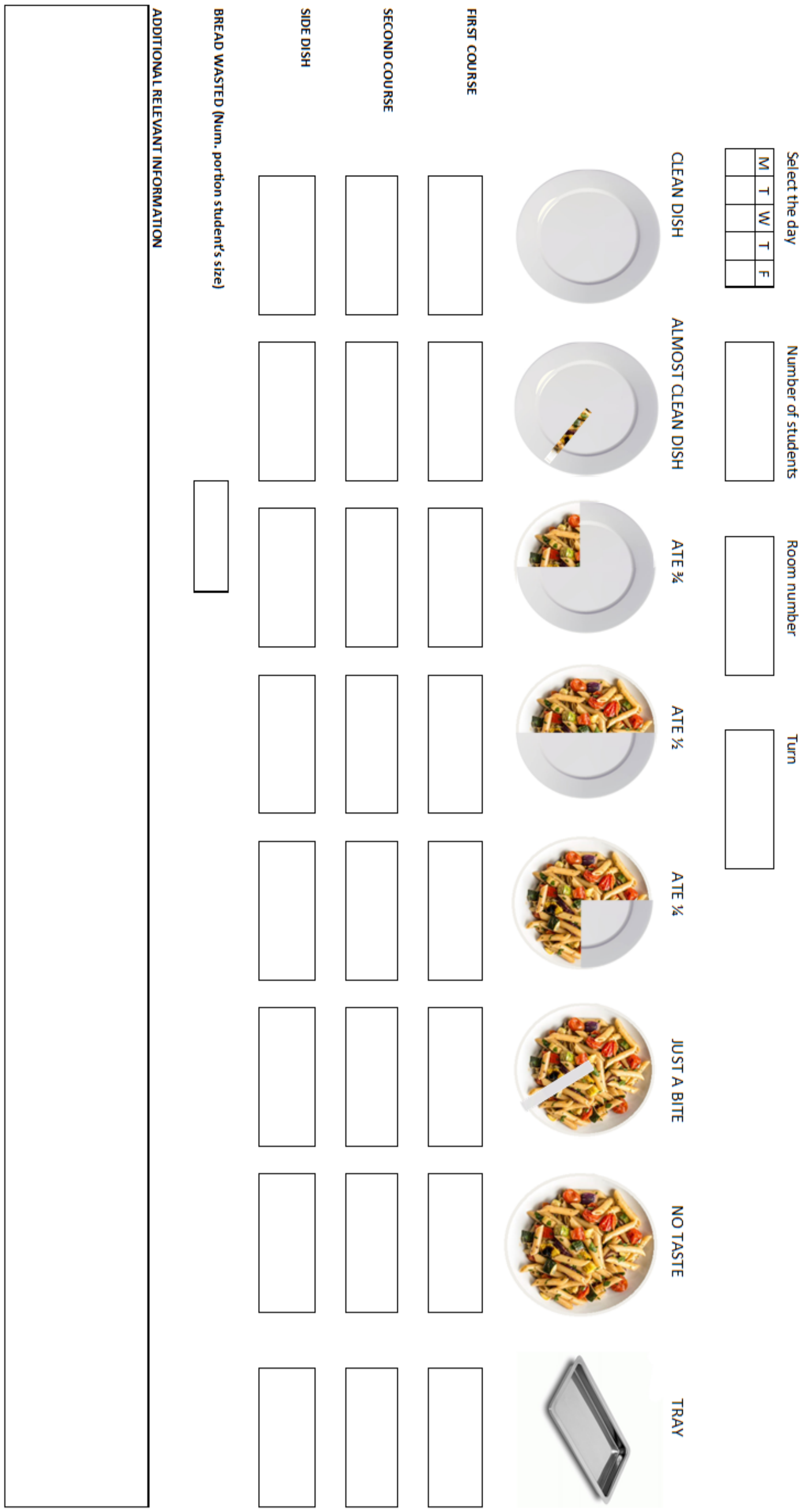
Life cycle sustainability assessment represents a valuable option to ensure a comprehensive understanding of the sustainability of the food supply chain. At the same time the lack of maturity of the social approach limits its full development and application. Further research should prioritize the social component from the development of tailored indicators to its full integration in a more holistic framework.

Additionally, more comprehensive policy frameworks could be developed by including additional nutritional and cultural parameters with the hotspots emerged in this research, as they represent key aspects for sustainable diets that were not covered in this study.

Annex – Chapter 1

A1 – Chapter 1. Template quarter-waste visual assessment

Template to assess food waste at school canteen by following the modified quarter-waste visual assessment.



A2 - Chapter 1. LCI Procurement phase

Environmental sources in the procurement phase.

Ingredient	Prep.waste	Fresh/frozen (F) /No fresh (NF) (*)	Environmental sources
Baked ham	10%	F	1 kg Pig meat, fresh, at slaughterhouse/NL Economic (of project Agri-footprint - economic allocation)
Basil	10%	F	1 kg Iceberg lettuce {GLO}| production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Bread	0%	F	EPD® Bread, Barilla - 234 Bakery products PCR 2012:06 version 2.0 29.05.2015
Bread crumbs	0%	NF	EPD® Bread, Barilla - 234 Bakery products PCR 2012:06 version 2.0 29.05.2015
Broth - Vegetable broth (prepared in the kitchen with various ingredients)	3%	F	Per 1kg = 150g onion + 100g tomato + 100g celery +150g carrot
Bullock	7%	F	1 kg Beef meat, fresh, from beef cattle, at slaughterhouse/IE Economic (of project Ecoinvent 3 - allocation, default - system) 1 kg Beef meat, fresh, from dairy cattle, at slaughterhouse/NL Economic (of project Agri-footprint - economic allocation)
Butter	0%	F	1 kg Butter, from cow milk {GLO}| production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Carrots	20%	F	1 kg Carrot {NL}| carrot production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Celery	15%	F	1 kg Celery {GLO}| 675 production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Clams	20%	F	Iribarren et al. 2011
Dried borlotti beans	0%	NF	1 kg Beans, dry, at farm/NL Economic (of project Agri-footprint - economic allocation)
Dried chickpeas	0%	NF	1 kg Chickpea, at farm/US Economic (of project Agri-footprint - economic allocation)
Eggplant	15%	F	1 kg Aubergine {GLO}| production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Emmenthal (Bavarian)	0%	F	1 kg Cheese, from cow milk, fresh, unripened {GLO}| cheese production, soft, from cow milk | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Fennel	20%	F	1 kg Fennel {GLO}| production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Fish	5%	F	Ziegler 2002

Ingredient	Prep.waste	Fresh/frozen (F) /No fresh (NF) (*)	Environmental sources
Fresh chard	40%	F	1 kg Spinach {GLO}∣ production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit) + impact of 1815kcal average italian electricity
Fresh fruit	0%	F	Average of: 1 kg Apple {IT}∣ apple production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit); 1 kg Apricot {IT}∣ apricot production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit); 1 kg Banana {EC}∣ banana production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit); 1 kg Grape {GLO}∣ production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit); 1 kg Kiwi {GLO}∣ production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit); 1 kg Mandarin {ES}∣ mandarin production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit); 1 kg Orange, fresh grade {ES}∣ orange production, fresh grade ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit); 1 kg Peach {IT}∣ peach production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit); 1 kg Pear {BE}∣ pear production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Frost spinach	30%	F	1 kg Spinach {GLO}∣ production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit) + impact of 1815kcal average italian electricity
Garlic	5%	F	Khoshnevisan and Rafiee, 2013
Grana Padano DOP	3%	F	1 kg Cheese, from cow milk, fresh, unripened {GLO}∣ cheese production, soft, from cow milk ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Green beans	5%	F	1 kg Fava bean, Swiss integrated production {RoW}∣ fava bean production, Swiss integrated production, at farm ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit) and 1 kg Fava bean, organic {RoW}∣ production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Iodized salt	0%	NF	1 kg Sodium chloride, powder {GLO}∣ market for ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Lemon juice	70%	F	1 kg Lemon {RoW}∣ lemon production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Mozzarella	0%	F	EPD® - Mozzarella 225 - Cheese, fresh or processed(unstats.un.org) S-P-00128
Olive oil	0%	NF	EPD® PCR 2010:07 (Version 2.1), CPC SUBCLASS 21537 VIRGIN OLIVE OIL AND ITS FRACTIONS. Geographic Scope: Europe and North America. S-P-OO410
Onion	5%	F	1 kg Onion {NL}∣ onion production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Organic cow ricotta	0%	F	EPD® 2225 - Riccota Granarolo- Cheese, fresh or processed. S-P-00825
Organic milk	0%	F	EPD® Code: 2211 - Processed liquid milk and cream. Registration numb. S-P-01042
Organic spelled	0%	NF	1 kg Wheat grain, at farm/IT Economic (of project Agri-footprint - economic allocation)

Ingredient	Prep.waste	Fresh/frozen (F) /No fresh (NF) (*)	Environmental sources
Organic wheat flour	0%	NF	1 kg Wheat flour, from dry milling, at plant/DE Economic (of project Agri-footprint - economic allocation)
Parsley	10%	F	1 kg Iceberg lettuce {GLO}| production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Pasta / pasta made from durum wheat semolina (also wholemeal)	0%	NF	EPD® PCR PCR 2010:01 VERSION 3.0 UN CPC 2371 Pasta di grano duro De Cecco
Pasteurized eggs	0%	F	1 p Consumption eggs, laying hens >17 weeks, at farm/NL Economic (of project Agri-footprint - economic allocation)
Pearl Barley	0%	NF	1 kg Barley grain, at farm/IT Economic (of project Agri-footprint - economic allocation)
Peas frost	0%	F	1 kg Pea, at farm/IT Economic (of project Agri-footprint - economic allocation) + impact of 1815kcal average italian electricity
Peppers	15%	F	1 kg Green bell pepper {GLO}| production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Pine nuts	0%	NF	1 kg Peanut {RoW}| peanut production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Pizza base	0%	F	1 kg Wheat flour, from dry milling, at plant/DE Economic (of project Agri-footprint - economic allocation)
Pork loin	15%	F	1 kg Pig meat, fresh, at slaughterhouse/NL Economic (of project Agri-footprint - economic allocation)
Potatoes	30%	F	1 kg Potato {RoW}| production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Pumpkin	25%	F	1 kg Zucchini {GLO}| production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Radish	5%	F	1 kg Chicory root, at farm/BE Economic (of project Agri-footprint - economic allocation)
Rice	0%	NF	1 kg Rice {RoW}| production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Rocket salad	10%	F	1 kg Iceberg lettuce {GLO}| production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Salad	7%	F	1 kg Iceberg lettuce {GLO}| production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Spinach	40%	F	1 kg Spinach {GLO}| production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Stracchino BIO	0%	F	EPD® 2225 Stracchino Cremoso Granarolo- Cheese, fresh or processed. Registration num. S-P-00823
Sweet corn	0%	F	1 kg Sweet corn {RoW}| sweet corn production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)

Ingredient	Prep.waste	Fresh/frozen (F) /No fresh (NF) (*)	Environmental sources
Tomato	5%	F	1 kg Tomato, processing grade {IT}｜tomato production, processing grade, open field｜Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Tomato pulp	0%	F	Del Borghi et al. 2014
Turkey breast	5%	F	1 kg Chicken meat, fresh, at slaughterhouse/NL Economic (of project Agri-footprint - economic allocation)
Vegetable granular broth / Extract of vegetable origin	0%	NF	Per 1kg = 150g onion + 100g celery +150g carrot
Walnuts	0%	NF	1 kg Peanut {RoW}｜peanut production｜Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Zucchini	15%	F	1 kg Zucchini {GLO}｜production｜Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Transport process (*)			
NF	1 kgkm Transport, freight, lorry 7.5-16 metric ton, EURO5 {GLO}｜market for｜Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)		
F	1 kgkm Transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO5, carbon dioxide, liquid refrigerant, freezing {GLO}｜market for transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO5, carbon dioxide, liquid refri(...)_16｜Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)		
References			
Khoshnevisan and Rafiee, 2013	Khoshnevisan, B., & Rafiee, S. (2013). Life cycle assessment of garlic production; a case study of Hamedan province, Iran. (November 2015).		
Del Borghi et al. 2014	An evaluation of environmental sustainability in the food industry through life cycle assessment: the case study of tomato products supply chain		
Iribarren et al. 2011	Life cycle assessment of mussel culture		
Ziegler 2002	Environmental Assessment of a Swedish, frozen cod product with a life-cycle perspective		

A3 – Chapter 1. LCI packaging

Environmental sources for packaging production and disposal.

Type of packaging	Production	Disposal
PP	1 kg Polypropylene, granulate {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	1 kg PP (waste treatment) {GLO}| recycling of PP | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
LDPE	1 kg Packaging film, low density polyethylene {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	1 kg PP (waste treatment) {GLO}| recycling of PP | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
HDPE	1 kg Polyethylene, high density, granulate {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	1 kg PP (waste treatment) {GLO}| recycling of PP | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
PS	1 kg Polystyrene, general purpose {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	1 kg PS (waste treatment) {GLO}| recycling of PS | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
PET	1 kg Polyethylene terephthalate, granulate, bottle grade {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	1 kg PET (waste treatment) {GLO}| recycling of PET | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Wood	0,0017 m3 Plywood, for outdoor use {RER}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	1 kg Core board (waste treatment) {GLO}| recycling of core board | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Paper	1 kg Kraft paper, bleached {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	1 kg Paper (waste treatment) {GLO}| recycling of paper | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Cardboard	1 kg Kraft paper, bleached {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	1 kg Paper (waste treatment) {GLO}| recycling of paper | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Glass	1 kg Packaging glass, white {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	1 kg Packaging glass, white (waste treatment) {GLO}| recycling of packaging glass, white | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Tin	1 kg Tin {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	1 kg Steel and iron (waste treatment) {GLO}| recycling of steel and iron | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Tetracart	Markwardt and Wellenreuther, 2017. Comparative Life Cycle Assessment of shelf stable canned food packaging - Tetra Recart. Institut für Energie- und Umwelttechnik	Markwardt and Wellenreuther, 2017. Comparative Life Cycle Assessment of shelf stable canned food packaging - Tetra Recart. Institut für Energie- und Umwelttechnik

A4 – Chapter 1. LCI other phases

Environmental sources for preparation, distribution and service phases – excluding packaging.

	Item	Source environmental impact
Preparation	Electricity	1 kWh Electricity, low voltage {IT}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
	Water	1 ton Tap water {Europe without Switzerland} | market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
	Gas	1 m3 Natural gas, high pressure {IT}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
	Cleaning products: dishes	EPD® PCR 2011:10 "DETERGENTS AND WASHING PREPARATIONS", VERSION 2.01, 2017-09-28 - VELVET
	Cleaning products: floor	EPD® PCR 2011:10 "DETERGENTS AND WASHING PREPARATIONS", VERSION 2.01, 2017-09-28 - TORRENT
	Packaging	See sheet A3_Packaging
	Waste water	1 m3 Wastewater, average {Europe without Switzerland} | treatment of wastewater, average, capacity 1E9l/year | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
	Organic waste	1 kg Biowaste {CH}| treatment of, composting | Conseq, U (of project Ecoinvent 3 - consequential - unit)
	Packaging disposal	See sheet A3_Packaging
Distribution	Full transportation	1 kgkm Transport, freight, light commercial vehicle {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
	Empty transportation	1 kgkm Transport, freight, light commercial vehicle {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Service	Water	1 ton Tap water {Europe without Switzerland} | market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
	Electricity	1 kWh Electricity, low voltage {IT}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
	Waste water	1 m3 Wastewater, from residence {RoW}| treatment of, capacity 1.1E10l/year | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
	Organic waste	1 kg Biowaste {CH}| treatment of, composting | Conseq, U (of project Ecoinvent 3 - consequential - unit)

A5 – Chapter 1. ANOVA and Kruskal-Wallis test between seasons

Statistic tests.

Nursery (winter-summer)

ANOVA: Single Factor								
Description								
Group	Count	Sum	Mean	Variance	SS	Std Err	Lower	Upper
Winter	900	27.642	0.031	0.002	1.352	0.001	0.0284	0.033
Summer	1026	24.490	0.023	0.001	1.058	0.001	0.0217	0.026
ANOVA								
Sources	SS	df	MS	F	P value	F crit	RMSSE	Omega Sq
Between Groups	0.022	1	0.022	17.931	2.398E-05	3.846	0.138	0.009
Within Groups	2.410	1924	0.001					
Total	2.432	1925	0.001					

Kruskal-Wallis Test

	Winter	Summer	
median	0	0	
rank sum	898109.5	957591.5	
count	900	1026	1926
r^2/n	896222971.1	893744133.4	1789967105
H-stat			6.464
H-ties			7.913
df			1
p-value			0.005
alpha			0.05
sig			yes

Since F > F crit, we can reject the null hypothesis. There are significant differences between the waste produced between seasons. Kruskal-Wallis also points the significant difference being p-value < alfa

Primary (winter-summer)

ANOVA: Single Factor								
Description								
Group	Count	Sum	Mean	Variance	SS	Std Err	Lower	Upper
Winter	3516	151.248	0.0430	0.003	11.136	0.001	0.041	0.045
Summer	3795	112.357	0.030	0.002	7.134	0.001	0.028	0.031
ANOVA								
Sources	SS	df	MS	F	P value	F crit	RMSSE	Omega Sq
Between Groups	0.328	1	0.328	131.308	3.831E-30	3.843	0.190	0.018
Within Groups	18.270	7309	0.002					
Total	18.599	7310	0.003					

Kruskal-Wallis Test

	Winter	Summer	
median	0	0	
rank sum	13666814	13062202	
count	3516	3795	7311
r^2/n	53123380236	44959452197	98082832434
H-stat			81.159
H-ties			99.652
df			1
p-value			1.816E-23
alpha			0.05
sig			yes

Since F > F crit, we can reject the null hypothesis. There are significant differences between the waste produced between seasons. Kruskal-Wallis also points the significant difference being p-value < alfa.

A6 – Chapter 1. Kolmogorov-Smirnov statistic test

Statistic tests applied to the food audit outcomes.

Primary summer	**First**			**Second**			**Side dish**					Alfa= 0.05
% Food waste (service)	Freq.	Prob.	Cumulative	Freq.	Prob.	Cumulative	Freq.	Prob.	Cumulative	Dif. Fir-Sec	Dif. Fir-Side	Dif. Sec-Side
0%	927	0.734	0.734	823	0.652	0.652	562	0.445	0.445	0.082	0.289	0.207
10%	61	0.048	0.782	22	0.017	0.669	53.	0.042	0.487	0.113	0.295	0.182
25%	63	0.050	0.832	57	0.045	0.714	66	0.052	0.539	0.118	0.293	0.175
50%	97	0.077	0.909	1110	0.088	0.802	116	0.092	0.631	0.107	0.278	0.171
75%	53	0.042	0.951	45	0.036	0.838	106	0.084	0.715	0.113	0.236	0.123
90%	47	0.037	0.988	63	0.050	0.888	133	0.105	0.820	0.101	0.168	0.067
100%	15	0.012	1.000	142	0.112	1.000	227	0.180	1.000	0.000	0.000	0.000
	1263	1		1263	1		1263	1	1263	1		
									D-stat	0.118	0.295	0.207
									D-crit	0.054		

Since Dstat > D-crit, we conclude there is a significant difference between the distributions for the samples.

Primary summer	**First**			**Second**			**Side dish**					Alfa= 0.05
% Food waste (service)	Freq.	Prob.	Cumulative	Freq.	Prob.	Cumulative	Freq.	Prob.	Cumulative	Dif. Fir-Sec	Dif. Fir-Side	Dif. Sec-Side
0%	814	0.696	0.696	694	0.593	0.593	349	0.298	0.298	0.103	0.397	0.295
10%	66	0.056	0.752	91	0.078	0.671	67	0.057	0.356	0.081	0.397	0.315
25%	70	0.060	0.812	71	0.061	0.732	70	0.060	0.415	0.080	0.397	0.316
50%	76	0.065	0.877	79	0.068	0.799	130	0.111	0.526	0.078	0.350	0.273
75%	51	0.044	0.921	39	0.033	0.832	74	0.063	0.590	0.088	0.331	0.243
90%	64	0.055	0.975	99	0.085	0.917	214	0.183	0.773	0.058	0.203	0.144
100%	29	0.025	1	97	0.083	1.000	266	0.227	1	0	0	0
	1170	1		1170	1		1170	1				
									D-stat	0.103	0.397	0.316
									D-crit	0.056		

Since Dstat > D-crit, we conclude there is a significant difference between the distributions for the samples.

Nursery summer	First			Second			Side dish					Alfa= 0.05
% Food waste (service)	Freq.	Prob.	Cumulative	Freq.	Prob.	Cumulative	Freq.	Prob.	Cumulative	Dif. Fir-Sec	Dif. Fir-Side	Dif. Sec-Side
0%	321	0.939	0.939	177	0.518	0.518	81	0.237	0.237	0.421	0.702	0.281
10%	1	0.003	0.942	31	0.091	0.608	12	0.035	0.272	0.333	0.670	0.336
25%	5	0.015	0.956	24	0.070	0.678	12	0.035	0.307	0.278	0.649	0.371
50%	6	0.018	0.974	39	0.114	0.792	6	0.018	0.325	0.181	0.649	0.468
75%	1	0.003	0.977	1	0.003	0.795	10	0.029	0.354	0.181	0.623	0.442
90%	0	0.000	0.977	2	0.006	0.801	33	0.096	0.450	0.175	0.526	0.351
100%	8	0.023	1.000	68	0.199	1.000	188	0.550	1.000	0.000	0.000	0.000
	342	1		342	1		342	1				
									D-stat	0.421	0.702	0.468
									D-crit	0.103		
				Since Dstat > D-crit, we conclude there is a significant difference between the distributions for the samples.								

Nursery winter	First			Second			Side dish					Alfa= 0.05
% Food waste (service)	Freq.	Prob.	Cumulative	Freq.	Prob.	Cumulative	Freq.	Prob.	Cumulative	Dif. Fir-Sec	Dif. Fir-Side	Dif. Sec-Side
0%	275	0.917	0.917	170	0.567	0.567	66	0.220	0.220	0.350	0.697	0.347
10%	3	0.010	0.927	18	0.060	0.627	0	0.000	0.220	0.300	0.707	0.407
25%	6	0.020	0.947	7	0.023	0.650	2	0.007	0.227	0.297	0.720	0.423
50%	3	0.010	0.957	26	0.087	0.737	18	0.060	0.287	0.220	0.670	0.450
75%	0	0.000	0.957	1	0.003	0.740	3	0.010	0.297	0.217	0.660	0.443
90%	4	0.013	0.970	20	0.067	0.807	29	0.097	0.393	0.163	0.577	0.413
100%	9	0.030	1.000	58	0.193	1.000	182	0.607	1.000	0.000	0.000	0.000
	300	1		300	1		300	1				
									D-stat	0.350	0.720	0.450
									D-crit	0.110		
				Since Dstat > D-crit, we conclude there is a significant difference between the distributions for the samples.								

Annex – Chapter 2

A1 – Chapter 2. Overall environmental impacts

Environmental impact per meal, user type and impact category.

		Elementary			
		GWP (kg CO_2-eq)	PQO (kg C_2H_4-eq)	AC (kg SO_2-eq)	EU (kg PO_4^{-3}-eq)
Procurement	Food procurement	1.11E+00	3.51E-04	1.22E-02	5.71E-03
	Packaging impact	3.66E-01	3.92E-04	7.36E-03	2.34E-03
	Transportation from wholesaler to school	3.50E-01	4.71E-05	1.11E-03	1.84E-04
Preparation	Packaging disposal	-2.38E-03	7.97E-05	5.34E-05	-4.27E-07
	Water (m3)	1.10E-08	2.47E-12	5.66E-11	2.18E-11
	Wastewater (m3)	1.78E-06	1.28E-09	4.88E-08	2.75E-07
	Gas (m3)	6.92E-05	1.34E-07	2.21E-06	4.83E-08
	Waste management (organic) - prep waste	1.53E-02	2.70E-06	1.31E-04	2.04E-05
	Electricity	3.66E-01	6.10E-05	1.34E-03	1.29E-03
	Cleaning products: dishes	9.76E-04	2.97E-07	4.57E-06	1.72E-06
	Cleaning products: floor	4.04E-04	1.22E-07	1.58E-06	6.57E-07
Service	Food waste - plate waste	5.32E-02	9.37E-06	4.54E-04	7.07E-05
	Food waste - serving waste	5.77E-03	1.02E-06	4.93E-05	7.68E-06
	Waste transportation from school to waste management	1.04E-02	1.89E-06	6.02E-05	1.00E-05
	Total	**2.28E+00**	**9.46E-04**	**2.28E-02**	**9.63E-03**

		Middle			
		GWP (kg CO_2-eq)	PQO (kg C_2H_4-eq)	AC (kg SO_2-eq)	EU (kg PO_4^{-3}-eq)
Procurement	Food procurement	1.05E+00	3.34E-04	1.18E-02	5.52E-03
	Packaging impact	3.39E-01	3.64E-04	6.83E-03	2.17E-03
	Transportation from wholesaler to school	3.50E-01	4.71E-05	1.11E-03	1.84E-04
Preparation	Packaging disposal	-2.21E-03	7.39E-05	4.95E-05	-3.96E-07
	Water (m3)	1.10E-08	2.47E-12	5.66E-11	2.18E-11
	Wastewater (m3)	1.78E-06	1.28E-09	4.88E-08	2.75E-07
	Gas (m3)	6.92E-05	1.34E-07	2.21E-06	4.83E-08
	Waste management (organic) - prep waste	1.53E-02	2.70E-06	1.31E-04	2.04E-05
	Electricity	3.66E-01	6.10E-05	1.34E-03	1.29E-03
	Cleaning products: dishes	9.76E-04	2.97E-07	4.57E-06	1.72E-06
	Cleaning products: floor	4.04E-04	1.22E-07	1.58E-06	6.57E-07
Service	Food waste - plate waste	4.63E-02	8.16E-06	3.95E-04	6.16E-05
	Food waste - serving waste	5.36E-03	9.44E-07	4.57E-05	7.12E-06
	Waste transportation from school to waste management	9.28E-03	1.69E-06	5.37E-05	8.92E-06
	Total	**2.18E+00**	**8.94E-04**	**2.18E-02**	**9.26E-03**

		High			
		GWP (kg CO_2-eq)	PQO (kg C_2H_4-eq)	AC (kg SO_2-eq)	EU (kg PO^{-3}_4-eq)
Procurement	Food procurement	1.14E+00	3.56E-04	1.27E-02	5.98E-03
	Packaging impact	3.82E-01	4.10E-04	7.70E-03	2.44E-03
	Transportation from wholesaler to school	3.50E-01	4.71E-05	1.11E-03	1.84E-04
Preparation	Packaging disposal	-2.49E-03	8.33E-05	5.58E-05	-4.46E-07
	Water (m3)	1.10E-08	2.47E-12	5.66E-11	2.18E-11
	Wastewater (m3)	1.78E-06	1.28E-09	4.88E-08	2.75E-07
	Gas (m3)	6.92E-05	1.34E-07	2.21E-06	4.83E-08
	Waste management (organic) - prep waste	1.53E-02	2.70E-06	1.31E-04	2.04E-05
	Electricity	3.66E-01	6.10E-05	1.34E-03	1.29E-03
	Cleaning products: dishes	9.76E-04	2.97E-07	4.57E-06	1.72E-06
	Cleaning products: floor	4.04E-04	1.22E-07	1.58E-06	6.57E-07
Service	Food waste - plate waste	3.60E-02	6.34E-06	3.07E-04	4.79E-05
	Food waste - serving waste	6.03E-03	1.06E-06	5.15E-05	8.03E-06
	Waste transportation from school to waste management	8.47E-03	1.54E-06	4.90E-05	8.13E-06
	Total	**2.30E+00**	**9.70E-04**	**2.35E-02**	**9.98E-03**

		Faculty			
		GWP (kg CO_2-eq)	PQO (kg C_2H_4-eq)	AC (kg SO_2-eq)	EU (kg PO^{-3}_4-eq)
Procurement	Food procurement	1.09E+00	3.76E-04	1.19E-02	5.48E-03
	Packaging impact	4.27E-01	4.58E-04	8.61E-03	2.73E-03
	Transportation from wholesaler to school	3.50E-01	4.71E-05	1.11E-03	1.84E-04
Preparation	Packaging disposal	-2.78E-03	9.32E-05	6.24E-05	-4.99E-07
	Water (m3)	1.10E-08	2.47E-12	5.66E-11	2.18E-11
	Wastewater (m3)	1.78E-06	1.28E-09	4.88E-08	2.75E-07
	Gas (m3)	6.92E-05	1.34E-07	2.21E-06	4.83E-08
	Waste management (organic) - prep waste	1.53E-02	2.70E-06	1.31E-04	2.04E-05
	Electricity	3.66E-01	6.10E-05	1.34E-03	1.29E-03
	Cleaning products: dishes	9.76E-04	2.97E-07	4.57E-06	1.72E-06
	Cleaning products: floor	4.04E-04	1.22E-07	1.58E-06	6.57E-07
Service	Food waste - plate waste	3.20E-02	5.63E-06	2.73E-04	4.25E-05
	Food waste - serving waste	6.75E-03	1.19E-06	5.76E-05	8.97E-06
	Waste transportation from school to waste management	8.45E-03	1.53E-06	4.89E-05	8.11E-06
	Total	**2.29E+00**	**1.05E-03**	**2.36E-02**	**9.76E-03**

A2 – Chapter 2. Mass flow

Amount and percentage of food per flow during data collection.

	Quantification (kg)	% purchased	% food served
Food purchase	6998.281314	100	
Food for next time	349.91	5	
Prep.waste	784	11	
Food served	5489.916187	78	
Serving waste	374.45	5	
Consumed	2907.561752	42	53
Plate Waste	2582.354434	37	47
Service stage: waste	2956.81		

Food consumed, wasted and served.

g/day	Eaten	Waste	Total	% waste
Elementary	228.738	262.592	491.329	53
Middle	227.052	228.638	455.689	50
High	335.861	177.679	513.540	35
Faculty	416.547	157.715	574.262	28

A3 – Chapter 2. Assumptions and sources

Data sources and assumptions made to calculate mass and cost inputs.

Item	Description
Purchased food type and mass	Provided by the school with their invoices and calculated during the FW audit. Note that the environmental impacts correspond to raw materials (not cooked) and some ready-to-eat meals might have been underestimated in the environmental evaluation as it does not included manufacturing inputs.
Packaging type and weight	Estimated according to the invoices and the most common packaging for each product.
Packaging disposal	Calculated by allocating to each packaging material the percentage of the connected waste management procedure indicated by US data (EPA, 2018). Three waste disposal paths have been considered: recycling, combustion and landfill. The cost is included in the tipping fee.
Food transportation from origin to school	Estimated by applying secondary source (Pirog and Benjamin, 2003).
Waste transportation from school to the disposal centre	20km was assumed as the distance from the school to the closest waste management facility carried out in a 21-metric ton lorry.
Cleaning products	Estimated by secondary sources, both quantity and cost according to the kitchen floor surface, and cooking tools and trays to clean up (Walmart, 2019a, 2019b).
Utilities: electricity, water and gas	Quantity and cost calculated from the invoices provided by the school referred to the whole school. The value corresponded to kitchen activities were distributed according to secondary sources (US.EIA, 2012a, 2012b; EPA, 2017).
Labor and other costs	The school pays a fixed price to the catering service per served meal. This cost includes kitchen labor, food purchase, administrative tasks, and profit. This cost item corresponds to the fixed price paid by the school subtracting the food purchase costing.

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A4 – Chapter 2. Food categories environmental sources

Environmental sources and weight per food category.

Category	kg purchased	Environmental sources
BEEF	216.341	1 kg Beef meat, fresh, from beef cattle, at slaughterhouse/IE Economic (of project Ecoinvent 3 - allocation, default - system)
		1 kg Beef meat, fresh, from dairy cattle, at slaughterhouse/NL Economic (of project Agri-footprint - economic allocation)
DAIRY - LIQUID	1397.574	1kg Cow milk {RoW}∣ milk production, from cow ∣ Alloc Def, U
DAIRY - SOLID	122.697	1 kg Cheese, from cow milk, fresh, unripened {GLO}∣ cheese production, soft, from cow milk ∣ Alloc Def, U
		1 kg Butter, from cow milk {GLO}∣ production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
EGG	118.734	1kg organic eggs. EPD 2013. 02310 - Hen eggs in shell fresh. S-P 00127
FISH	104.837	1kg cod fish. Ziegler 2002
FRUIT	1329.511	1 kg Banana {EC}∣ banana production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
		1 kg Grape {GLO}∣ production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
		1 kg Apple {GLO}∣ market for ∣ Alloc Def, U; Heat, district or industrial, natural gas {GLO}∣ market group for ∣ Alloc Def, U Electricity, low voltage {US}∣ market group for ∣ Alloc Def, U; Steam, in chemical industry {GLO}∣ market for ∣ Alloc Def, U
		1 kg Applesauce=50% apple + 50% sugar
		1 kg Fruit cocktail=30% peach+30% pear+30%pinapple+10% apple
		1 kg Melon {GLO}∣ market for ∣ Alloc Def, U
		1 kg Orange, fresh grade {US}∣ orange production, fresh grade ∣ Alloc Def, U
		1 kg Peach {IT}∣ peach production ∣ Alloc Def, U
		1 kg Pear {GLO}∣ market for ∣ Alloc Def, U
		1 kg Pineapple {GLO}∣ market for ∣ Alloc Def, U
		1 kg Strawberry {US}∣ strawberry production, open field, macro tunnel ∣ Alloc Def, U
MISCELLANEOUS	524.133	1 l Drink mix=30% apple juice+30% peach juice+10% strawberry juice+30% sugar. Juices from Hegger and Haan, 2015
		1 kg alternative meat Smetana et al. 2015
		1 kg Peanut {RoW}∣ peanut production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
		1 kg Rice {RoW}∣ production ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
		1 kg Sodium chloride, powder {GLO}∣ market for ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)

Category	kg purchased	Environmental sources
		1 kg oil EPD® PCR 2010:07 (Version 2.1), CPC SUBCLASS 21537 VIRGIN OLIVE OIL AND ITS FRACTIONS. Geographic Scope: Europe and North America. S-P-OO410
		1 l Lemon juice= 60% lemon juice+40% sugar. Juice from Hegger and Haan, 2015
		1 kg Sugar, from sugarcane {GLO}| market for | Alloc Def, U
		1 l Gravy. Per 1l: 150g onion + 150g celery +150g carrot
		1 kg margarine. Nilsson et al, 2010 (UK margarine)
		1 kg tomatoe puree. Manfredi et al. 2014
		1 kg organic eggs. EPD 02310 - Hen eggs in shell fresh
		1 kg Iceberg lettuce {GLO}| production | Alloc Def, U
		1 kg bread. CPC 234 Bakery products PCR 2012:06 v. 2.0 29.05.2015 white bread
		1 l Apple juice Hegger and Haan, 2015
		1 kg Grape {GLO}| production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
		1 kg Chicken meat, fresh, at slaughterhouse/NL Economic (of project Agri-footprint - economic allocation)
OIL	101.357	1 kg Olive oil EPD® PCR 2010:07 (Version 2.1), CPC SUBCLASS 21537 VIRGIN OLIVE OIL AND ITS FRACTIONS. Geographic Scope: Europe and North America. S-P-OO410
PORK	239.347	1 kg Swine for slaughtering, live weight {GLO}| market for | Alloc Def, U
POULTRY	433.356	1 kg Chicken meat, fresh, at slaughterhouse/NL Economic (of project Agri-footprint - economic allocation)
SUGAR	54.319	1kg Sugar, from sugarcane {GLO}| market for | Alloc Def, U
VEGETABLE	1556.203	1kg Cucumber {GLO}| market for | Alloc Def, U
		1 kg Green bell pepper {GLO}| production | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
		1 kg Maize flour, from dry milling, at plant/US Economic
		1 kg Olive {IT}| olive production | Alloc Def, U
		1 kg Broccoli {GLO}| market for | Alloc Def, U
		1 kg Celery {GLO}| 675 production | Alloc Def, U
		1 kg garlic. Khoshnevisan and Rafiee, 2013
		1 kg tomatoe puree. Manfredi et al. 2014
		1 kg Protein pea {GLO}| market for | Alloc Def, U
		1 kg Onion {GLO}| market for | Alloc Def, U
		1 kg Iceberg lettuce {GLO}| production | Alloc Def, U

Category	kg purchased	Environmental sources
		1 kg Carrot {GLO}│ market for │ Alloc Def, U
		1 kg Tofu {GLO}│ market for │ Alloc Def, U
		1kg Sweet corn {RoW}│ sweet corn production │ Alloc Def, U
		1kg Fava bean, Swiss integrated production {RoW}│ fava bean production, Swiss integrated production, at farm │ Alloc Def, U
		1 kg Potato {RoW}│ production │ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
		1kg tomato puree. Manfredi et al. 2014
		1 kg Zucchini {GLO}│ production │ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
		1kg Tomato, fresh grade {MX}│ tomato production, fresh grade, open field │ Alloc Def, U
		1 kg Spinach {GLO}│ production │ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
WHEAT	799.874	1 kg pasta. EPD DURUM PASTA REGISTRATION NUMBERS-P-00230.EPD 2017 - Durum wheat semolina pasta in paperbox.
		1 kg bread. CPC 234 Bakery products PCR 2012:06 v. 2.0 29.05.2015 white bread
		1 kg Wheat flour, from dry milling, at plant/DE Economic (of project Agri-footprint - economic allocation) --60% wheat

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A5 – Chapter 2. LCI stages

Environmental sources considered. Excluding food categories.

Item	Source
Water (m^3)	Tap water {GLO}∣ market group for ∣ Alloc Rec, U
Waste water (m^3)	Wastewater, average {CA-QC}∣ treatment of wastewater, average, capacity 1.1E10l/year ∣ Alloc Def, U
Gas (m^3)	Natural gas, high pressure {US}∣ market for ∣ Alloc Def, U
Waste management (organic) - prep waste	1 kg Biowaste {RoW}∣ treatment of, composting ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Electricity	Electricity, low voltage {US}∣ market group for ∣ Alloc Def, U
Cleaning products: dishes	EPD® PCR 2011:10 "DETERGENTS AND WASHING PREPARATIONS", VERSION 2.01, 2017-09-28 - TORRENT
Cleaning products: floor	EPD® PCR 2011:10 "DETERGENTS AND WASHING PREPARATIONS", VERSION 2.01, 2017-09-28 - VELVET
Waste collection truck	1 kgkm Municipal waste collection service by 21 metric ton lorry {RoW}∣ processing ∣ Alloc Rec, U (of project Ecoinvent 3 - allocation, recycled content - unit)
Landfill PP	1 kg Waste polypropylene {CH}∣ treatment of, sanitary landfill ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Landfill LDPE	1 kg Waste polyethylene {RoW}∣ treatment of waste polyethylene, sanitary landfill ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Landfill PS	1 kg Waste polystyrene {RoW}∣ treatment of waste polystyrene, sanitary landfill ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Landfill HDPE	1 kg Waste polyethylene terephtalate {RoW}∣ treatment of waste polyethylene terephtalate, sanitary landfill ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Landfill carboard	1 kg Waste paperboard {RoW}∣ treatment of, sanitary landfill ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Landfill glass	1 kg Waste glass {CH}∣ treatment of, inert material landfill ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Landfill tin	1 kg Scrap tin sheet {CH}∣ treatment of, sanitary landfill ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Tetrarecart production and disposal	Markwardt and Wellenreuther, 2017. Comparative Life Cycle Assessment of shelf stable canned food packaging - Tetra Recart. Institut für Energie- und Umwelttechnik
Combustion PP	1 kg Waste polypropylene {CH}∣ treatment of, municipal incineration ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - system)
Combustion LDPE	1 kg Waste polyethylene {RoW}∣ treatment of waste polyethylene, municipal incineration ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Combustion PS	1 kg Waste polystyrene {RoW}∣ treatment of waste polystyrene, municipal incineration ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Combustion HDPE	1 kg Waste polyethylene terephtalate {RoW}∣ treatment of waste polyethylene terephtalate, municipal incineration ∣ Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)

Item	Source
Combustion carboard	1 kg Waste paperboard {RoW}| treatment of, municipal incineration | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Combustion glass	1 kg Waste glass {RoW}| treatment of waste glass, municipal incineration | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Combustion tin	1 kg Scrap tin sheet {CH}| treatment of, municipal incineration | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Recycling PP	1 kg PP (waste treatment) {GLO}| recycling of PP | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Recycling PE	1 kg PE (waste treatment) {GLO}| recycling of PE | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Recycling PS	1 kg PS (waste treatment) {GLO}| recycling of PS | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Recycling PET	1 kg PET (waste treatment) {GLO}| recycling of PET | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Recycling carboard/paper	1 kg Core board (waste treatment) {GLO}| recycling of core board | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
	1 kg Paper (waste treatment) {GLO}| recycling of paper | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Recycling glass	1 kg Packaging glass, white (waste treatment) {GLO}| recycling of packaging glass, white | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Recycling tin	1 kg Steel and iron (waste treatment) {GLO}| recycling of steel and iron | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Production PP	1 kg Polypropylene, granulate {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Production LDPE	1 kg Packaging film, low density polyethylene {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Production HDPE	1 kg Polyethylene, high density, granulate {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Production PS	1 kg Polystyrene, general purpose {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Production PET	1 kg Polyethylene terephthalate, granulate, bottle grade {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Production carboard/paper	1 kg Kraft paper, bleached {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Production glass	1 kg Packaging glass, white {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Production tin	1 kg Tin {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)
Transportation from field to school	1 kgkm Transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO5, carbon dioxide, liquid refrigerant, cooling {GLO}| market for transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO5, carbon dioxide, liquid refrig(...)_8 | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)

Packaging management percentages

Material	%recycled	%Combusted	%Landfilled
Paper and paperboard	66,598	6,539	26,863
Glass	26,417	12,816	60,767
Steel	33,352	11,778	54,871
Plastics	9,101	15,507	75,391
Miscellaneous inorganic wastes	0,000	19,549	80,451

Source: https://www.epa.gov/sites/production/files/2018-07/documents/2015_smm_msw_factsheet_07242018_fnl_508_002.pdf

A6 – Chapter 2. FW Embedded environmental impact

Embedded environmental impact per stage, meal and user type.

		GWP (kg CO_2-eq)	PQO (kg C_2H_4-eq)	AC (kg SO_2-eq)	EU (kg PO_4^{-3}-eq)
Elementary	Food waste - prep	1.53E-02	2.70E-06	1.31E-04	2.04E-05
	Food waste - plate waste	5.32E-02	9.37E-06	4.54E-04	7.07E-05
	Food waste - serving waste	5.77E-03	1.02E-06	4.93E-05	7.68E-06
	Packaging impact	2.24E-01	2.40E-04	4.51E-03	1.43E-03
	All prep stage except waste management	2.24E-01	8.65E-05	8.59E-04	7.91E-04
	Waste transportation from school to waste management	1.04E-02	1.89E-06	6.02E-05	1.00E-05
	Food production - all waste flows	8.03E-01	3.54E-04	8.41E-03	5.78E-03
	Total	1.34E+00	6.95E-04	1.45E-02	8.11E-03
Middle	Food waste - prep	1.53E-02	2.70E-06	1.31E-04	2.04E-05
	Food waste - plate waste	4.63E-02	8.16E-06	3.95E-04	6.16E-05
	Food waste - serving waste	5.36E-03	9.44E-07	4.57E-05	7.12E-06
	Packaging impact	2.01E-01	2.16E-04	4.05E-03	1.28E-03
	All prep stage except waste management	2.17E-01	8.04E-05	8.30E-04	7.66E-04
	Waste transportation from school to waste management	9.28E-03	1.69E-06	5.37E-05	8.92E-06
	Food production - all waste flows	7.31E-01	3.22E-04	7.66E-03	5.26E-03
	Total	1.23E+00	6.32E-04	1.32E-02	7.41E-03
High	Food waste - prep	1.53E-02	2.70E-06	1.31E-04	2.04E-05
	Food waste - plate waste	3.60E-02	6.34E-06	3.07E-04	4.79E-05
	Food waste - serving waste	6.03E-03	1.06E-06	5.15E-05	8.03E-06
	Packaging impact	1.76E-01	1.88E-04	3.54E-03	1.12E-03
	All prep stage except waste management	1.68E-01	6.66E-05	6.46E-04	5.94E-04
	Waste transportation from school to waste management	8.47E-03	1.54E-06	4.90E-05	8.13E-06
	Food production - all waste flows	6.26E-01	2.76E-04	6.55E-03	4.50E-03
	Total	1.04E+00	5.42E-04	1.13E-02	6.30E-03
Faculty	Food waste - prep	1.53E-02	2.70E-06	1.31E-04	2.04E-05
	Food waste - plate waste	3.20E-02	5.63E-06	2.73E-04	4.25E-05
	Food waste - serving waste	6.75E-03	1.19E-06	5.76E-05	8.97E-06
	Packaging impact	1.67E-01	1.79E-04	3.36E-03	1.07E-03
	All prep stage except waste management	1.43E-01	6.05E-05	5.52E-04	5.05E-04
	Waste transportation from school to waste management	8.47E-03	1.54E-06	4.90E-05	8.13E-06
	Food production - all waste flows	5.84E-01	2.57E-04	6.11E-03	4.20E-03
	Total	9.56E-01	5.08E-04	1.05E-02	5.85E-03

A7 – Chapter 2. Waste Management processing and its contribution (%) to the environmental impact

Percentage of environmental impact per user type and impact category in waste phases.

User type	WM	GWP (%)	PQO (%)	AC (%)	EU (%)
Elementary	WM - prep waste	19	3	17	19
	WM - packaging	-3	84	7	0
	WM - plate waste	65	10	61	65
	WM - serving waste	7	1	7	7
	Waste transportation to waste disposal	13	2	8	9
Middle	WM - prep waste	19	3	18	20
	WM - packaging	-3	85	7	0
	WM - plate waste	64	9	59	64
	WM - serving waste	7	1	7	7
	Waste transportation to waste disposal	13	2	8	9
High	WM - prep waste	25	3	23	25
	WM - packaging	-4	88	9	-1
	WM - plate waste	56	7	51	56
	WM - serving waste	9	1	9	9
	Waste transportation to waste disposal	13	2	8	10
Faculty	WM - prep waste	29	3	26	29
	WM - packaging	-4	89	11	-1
	WM - plate waste	51	5	46	51
	WM - serving waste	11	1	10	11
	Waste transportation to waste disposal	14	1	8	10

A7 – Chapter. 2. Proposal intervention matrix

Proposed scores per driver of change.

Drivers of change	**Main characteristics**			
Institution	Level of institution involved to promote the intervention.	School		Higher level
		1		2
Economic and human resources	There is a need to budget the proposal intervention. Low cost indicates budget which could be easily assumed by the school, while high indicates external aids.	No cost		Cost
		1		2
	Expertise - The intervention requires advanced knowledge level on nutrition/environmental or economic management	No expertise		Expertise
		1		2
	Time - Approximate time to implement the intervention in months.	-6M		>+6M
		1		2
Parents' engagement	The involvement of parents is key to the intervention success.	No need		Need
		1		2
Teachers' engagement	Support at classroom is needed to achieve the intervention.	No need		Need
		1		2

- Scores from 6-8 low (L) complexity of implementation.
- Scores from 9-10 medium (M) complexity of implementation.
- Scores from 11-12 high (H) complexity of implementation.

Intervention and evaluation matrix: a preliminary assessment

Hotspot	Intervention	Case of success	Evaluation
Large amount of plate waste	Adapt the amount of certain food served by reviewing the school meal planning.	Modifying food composition could lead in an increase in vegetable consumption (Cohen *et al.*, 2014)	**8**
	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.	It has been effective to reduce plate waste in University canteens (Whitehair, Shanklin and Brannon, 2013; Goldberg *et al.*, 2015).	**8**
	Reduce the amount of food served per food item.	Reduced food amounts might reduce more than 50% food waste (Reynolds *et al.*, 2019).	**6**
	Improve food quality and national food policies.	Improvements in food quality, satiation and policies and (Zhao *et al.*, 2019)	**11**
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	In this study, mentioned FW flows represents about 21% of FW, results aligned with other studies. Conscious food practices might lead to a 10% prep waste reduction (Tóth *et al.*, 2017).	**7**
Serving waste	Reduce the amount of buffet options after assessing which food items are wasted the most.	Main drivers of food waste were buffet options and overproduction (Silvennoinen *et al.*, 2015).	**6**
Environmental impact due to animal-based products	Internal Measures: Reduce the animal-based food products - Substitute a percentage of animal-based products with plant-based, following nutritional guidelines.	Lower environmental impact meals are associated with healthier meals. A 25-50% meal substitution of animal-based products with plant-based could reduce greenhouse emissions 25-40% (Westhoek *et al.*, 2014; Seconda *et al.*, 2018).	**7**
Environmental impact due to transportation	Shortening the food supply chain - Prioritize the purchase of products produced within the State of Missouri and surrounding states.	This exercise will help to understand the food security of the area as well as to reduce the environmental impact associated with transportation (Li *et al.*, 2019; Malak-Rawlikowska *et al.*, 2019).	**6**
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.	Reduce meat products by including other more environmentally friendly ones. Climate change tax to beef could lead to a 23-35% emissions reduction (Gren *et al.*, 2019).	**12**
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. Thus, a balance to	Alternative diets decreasing animal-based products might lead to 1/3 of economic savings, and health cost reductions, keeping nutritional adequate the nutritional values (Chen, Chaudhary and Mathys, 2019).	**8**

Hotspot	Intervention	Case of success	Evaluation
	satisfy cost-environmental nutrition and cultural aspects should be carefully reviewed. A proposal starts, besides animal-based product reduction, with a substitution of miscellaneous foods such as vegetable burgers with other preparations with same nutritional performance but less price, and same or less impact.	Financial incentives might reduce meat consumption (Wynes *et al.*, 2018). It is possible to reach an environmentally friendly diet without increasing food budget (with a wide range of budget) (Ribal et al., 2016). Re-thinking diets should include the nutritional contribution per mass of product (González-García *et al.*, 2018)	**9**
Food waste Environmental impact	Sustainability plan. Develop an integrated sustainability plan to integrate all school activities, including the canteen service. The plan could address social, economic and environmental aspects with key performance indicators.	Target directly measures to reduce food waste officially. A preliminary assessment, like the one conducted in this research, is key to set the baseline scenario.The study of Liz-Martins et al. (2016) shows that training to teachers, in long term, could help reducing food waste.	10
Cost impact	Follow the prioritizing food waste routes, from prevention, to recovery (food donation), and recycling (for example in compost).	The food waste platform provides 27 solutions to target FLW following the prioritization order based on the (ReFED, 2019)	**6**

A8 – Chapter 2. Statistic test

Statistic test applied to the food waste audit outcomes.

ANOVA: Single Factor

DESCRIPTION					Alpha	0.05		
Group	Count	Sum	Mean	Variance	SS	Std Err	Lower	Upper
0	13	100	7.692	152.160	1825.922	3.250	1.228	14.156
0	13	100	7.692	144.427	1733.131	3.250	1.228	14.156
3.662	13	96.337	7.410	162.648	1951.784	3.250	0.946	13.874
0	13	100	7.692	181.356	2176.276	3.250	1.228	14.156
0	13	100	7.692	99.036	1188.435	3.250	1.228	14.156
0.093	13	99.906	7.685	101.881	1222.575	3.250	1.220	14.149
4.994	13	95.005	7.308	120.027	1440.328	3.250	0.843	13.772

ANOVA								
Sources	SS	df	MS	F	P value	F crit	RMSSE	Omega Sq
Between Groups	2.109	6	0.351	0.003	1	2.208	0.0140	-0.071
Within Groups	11538.452	84	137.362					
Total	11540.561	90	128.228					

Kruskal-Wallis Test

median	0.611	0.668	1.188	0	0	1.286881	0.853	
rank sum	629	616	621	501	551	650	618	
count	13	13	13	13	13	13	13	91
r^2/n	30433.92	29188.92	29664.69	19307.77	23353.92	32500	29378.77	193828
H-stat								1.823
H-ties								1.914
df								6
p-value								0.927
alpha								0.05
sig								no

A9 – Chapter 2. Nutritional features

Nutritional features per food category.

Food category	Average						
	Proteins (g)	**Total lipid (fat) (g)**	**Carbohydrate, by difference**	**Energy (Kcal)**	**Total sugars (g)**	**Sodium (mg)**	**Saturated fat (g)**
BEEF	24,890	8,595	0,895	179,500	0,000	346,500	3,550
DAIRY - LIQUID	4,284	10,425	6,966	137,250	5,024	180,250	5,988
DAIRY - SOLID	18,086	25,624	5,991	325,000	2,296	761,778	15,989
EGG	12,380	10,040	1,280	146,000	1,163	132,000	3,133
FISH	17,550	4,888	9,153	151,500	0,445	137,500	1,600
FRUIT	0,620	0,178	13,315	52,231	8,580	6,308	0,008
MISC	8,999	10,279	39,969	279,028	12,355	2473,917	1,936
OIL	0,681	61,561	6,183	580,143	5,778	437,429	9,943
PORK	12,556	20,994	6,493	266,857	1,576	847,286	7,086
POULTRY	18,043	10,278	3,312	179,667	0,582	581,833	2,517
SUGAR	1,359	7,979	65,722	335,417	46,859	76,083	5,867
VEGETAB LE	2,977	3,331	11,226	82,150	2,443	205,950	0,575
WHEAT	8,059	11,533	57,651	366,786	9,343	340,671	51,131
Total	**7,052**	**11,076**	**24,331**	**221,137**	**9,140**	**779,406**	**7,628**
Sources: USDA Research service National Nutrient Database for Standard Reference Legacy Release (new) and https://www.prairiefarms.com/wp-content/uploads/2016/01/milk-Premium-Chocolate.pdf (chocolate milk, within Dairy liquids)							