

Review

The Use of Life Cycle-Based Approaches in the Food Service Sector to Improve Sustainability: A Systematic Review

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Abstract: With the prevalence of eating out increasing, the food service sector has an increasing role in accelerating the transition towards more sustainable and healthy food systems. While life cycle-based approaches are recommended to be used as reference methods for assessing the environmental sustainability of food systems and supply chains, their application in the food service sector is still relatively scarce. In this study, a systematic review was conducted to examine the use and effectiveness of life-cycle based interventions in improving the sustainability of food services. This review found that life-cycle based approaches are not only useful for identifying hotspots for impact reduction, but also for comparing the performance of different sustainability interventions. In particular, interventions targeting the production phase, such as promoting dietary change through menu planning in which high-impact ingredients (e.g., animal products) are replaced with low-impact ingredients (e.g., plant foods), had the highest improvement potential. Interventions targeting other phases of the catering supply chain (e.g., food storage, meal preparation, waste management) had considerably lower improvement potentials. This review article provides valuable insights on how the sustainability of the food service sector can be improved without the burden shifting of impacts, which interventions to prioritise, and where knowledge gaps in research exist. A key recommendation for future research is to focus on combined life cycle thinking approaches that are capable of addressing sustainability holistically in the food service sector by integrating and assessing the environmental, social and economic dimensions of interventions.

Keywords: food service; life cycle thinking; LCA; food systems; health; sustainability

1. Introduction

The food system is at the heart of some of the greatest global environmental and health challenges we face today. On the one hand, the food system is the single biggest contributor to climate change, responsible for about one third of global anthropogenic greenhouse gas (GHG) emissions [1,2]. Livestock alone accounts for approximately half of these emissions [3]. In addition, livestock is also the single largest user of land, a major driver of biodiversity loss, deforestation, land degradation and pollution [4]. The significant negative impacts of the current food system, ranging from the depletion and inefficient use of natural resources to terrestrial and aquatic biodiversity loss and the degradation of land, ecosystem services, air, soil and water quality [5], are also unmistakable.

Meanwhile, the food system is also struggling to promote human health and well-being, not to mention animal rights and welfare. Modern dietary transitions, in which traditional diets are progressively being replaced by diets high in processed foods, refined sugars, fats, oils, meat, dairy and

animal products, are not only linked with obesity and other diet-related chronic diseases such as cancer, cardiovascular disease, stroke and diabetes [6,7] but are also associated with higher environmental impacts [8].

As the prevalence of eating out of home increases, the food service sector is becoming one of the major supply channels of food, especially in cities and urban areas [9,10]. The food service sector, also sometimes called the catering sector (British English) or foodservice sector (US English), refers to the industry that gives the serviced provision of food and beverages (meals) prepared and served outside of home [11]. The food service sector is highly diverse, and is composed of a range of eating establishments that can be divided into two main categories (see Figure 1). The private or commercial (profit) sector is made up of various types of restaurants, cafes, bars, fast foods outlets and chain outlets. The public or institutional (sometimes also called cost/welfare) sector consists of various food service outlets provided by public institutions such as hospitals, schools and universities, care homes, prisons, etc. [12].

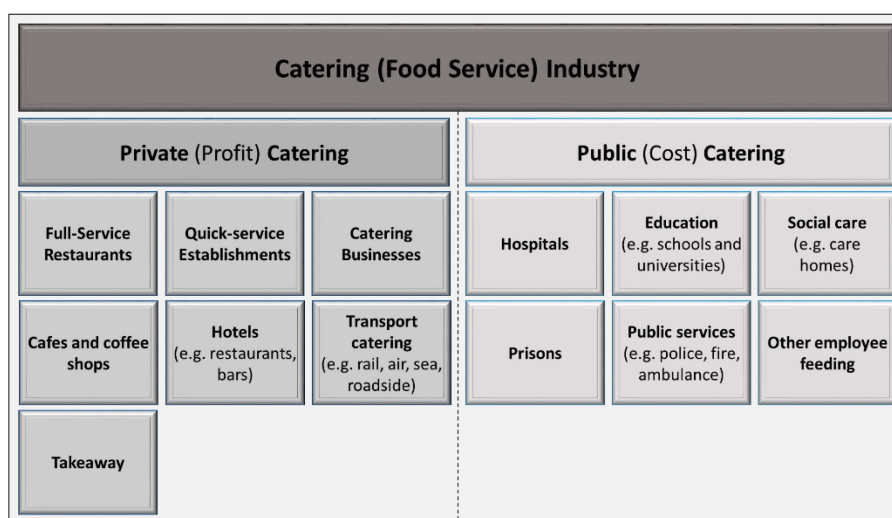


Figure 1. Different types of catering establishments (after Edwards and Overstreet [12]).

With a value of US\$3.4 trillion [10], the global food service market makes up about 40 percent of the global food and agriculture industry. Due to the size and value of this sector, food service businesses have an increasing potential to accelerate change and influence both the production and consumption side of the food system. On the one hand, they can increase the efficiency of food supply chains and support sustainable food production practices through various supply chain interventions [13], while on the other hand they can promote sustainable consumption, drive dietary change, influence eating habits and shift consumer preferences through carefully planned offers [14,15].

While the catering sector is in a unique position to drive sustainability in both the production and consumption side of the food system, research to date is still relatively scarce on how this sector can manage resources efficiently and replace carbon intensive operations to mitigate climate change and other negative environmental and social impacts of the food system [16,17]. There are numerous strategies and interventions available to food service businesses to improve the sustainability of their operations (see Figure 2). In the UK, for example, various procurement strategies (e.g., purchasing seasonal produce, obtaining certain percentages of organic and local food, etc.) and resource management strategies (e.g., reducing food waste and improving energy efficiency) are considered best practice in the catering sector, and organisations are encouraged to follow such practices [18].

However, the environmental benefits achieved by the adoption of such practices and their effectiveness in reducing impacts from catering operations are rarely evaluated and assessed quantitatively. As it will be evident from this systematic review, different interventions are not created equal and they all have different mitigation and sustainability improvement potentials. To evaluate and assess the effectiveness of sustainability interventions, systems-based and life cycle thinking approaches

such as life cycle assessment (LCA) are necessary. Such approaches are capable of assessing a wide range of impacts of a system over its whole life (from production, distribution through consumption and disposal) in an integrated way without the burden shifting of impacts across different stages and/or impact categories and thus improving the sustainability of the whole system [19]. Consequently, life cycle-based approaches are recommended to be used as a reference method for environmental impact assessment of food products, food systems and supply chains [20]. Nevertheless, its application in the catering sector is still relatively scarce [21]. Carino et al. [22], for example, recently conducted a systematic review on the environmental sustainability of hospital food services, and found that most studies did not quantify the environmental impacts (e.g., of procured food in hospital food services) using LCA. Without the quantification of environmental impacts, it is difficult to make informed decisions on how best to promote environmental sustainability across catering supply chains.

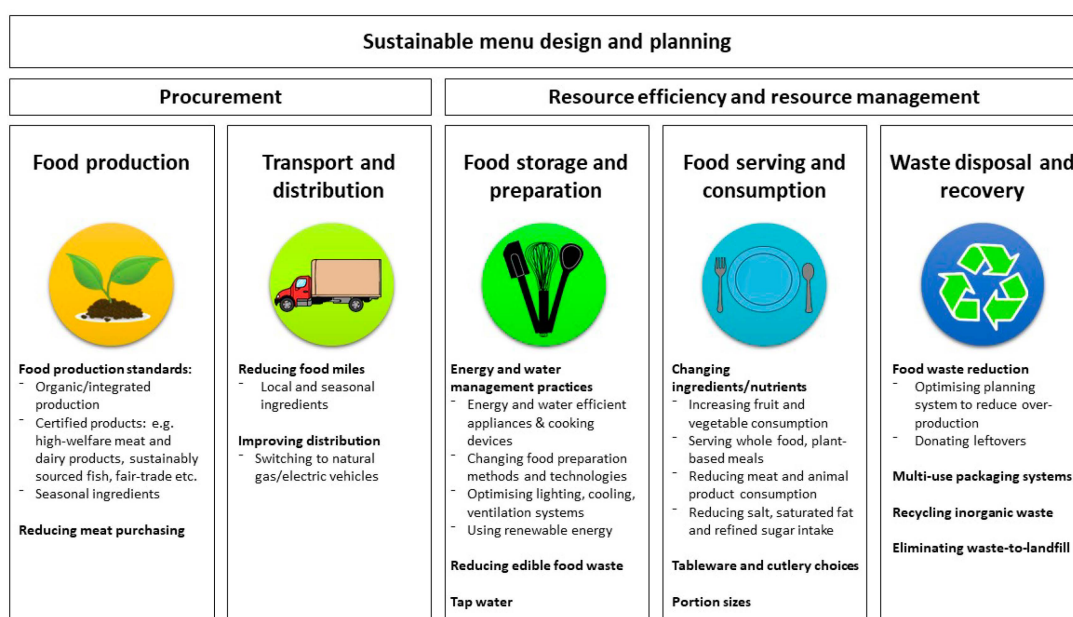


Figure 2. Possible sustainability interventions in the food service sector.

To our knowledge, no systematic reviews have been carried out to date on the application of life cycle thinking in the food service sector, despite such information being crucial for making informed decisions on how best to improve the sustainability of this sector. With this knowledge gap in mind, this review article aims to synthesise research to date on the application of life cycle thinking in the food service sector. More specifically, the objective of this systematic review is to report on the findings of peer-reviewed journal articles published between 2000 and 2019 that assess the impact of catering supply chains and operations using life cycle-based approaches. The effectiveness of different life cycle-based interventions in reducing the negative impacts of catering operations is also evaluated. Such information is crucial for knowing which interventions to prioritise in order to maximise the reduction of negative impacts and improve sustainability across the whole catering supply chain without the burden shifting of impacts. In this paper, the term “intervention” refers to any potential change in catering processes, and is not limited to actual, real-life interventions that have already been implemented.

The remainder of this article is structured as follows: Section 2 provides an overview of the methods employed in this systematic review, and describes the review protocol, the search strategy and coding procedures used in this research. Section 3 presents and discusses the results of this systematic review. Research gaps and recommendations for future research directions are highlighted along the way when appropriate. Finally, the main conclusions are summarised in Section 4.

2. Methods

This systematic review was carried out following the PRISMA guidelines [23]. In this review, peer-reviewed articles published between 2000 and until the end of 2019 were reviewed that use life cycle-based interventions to assess and improve the sustainability of the food service sector. The literature search was performed in October 2019 using the following three databases: Scopus, Web of Science and Science Direct. Multiple databases and search tools were used to prevent errors and reduce the possibility of bias in the retrieved results as much as possible. All searches were conducted in English language. The process of the literature search is summarised in Figure 3.

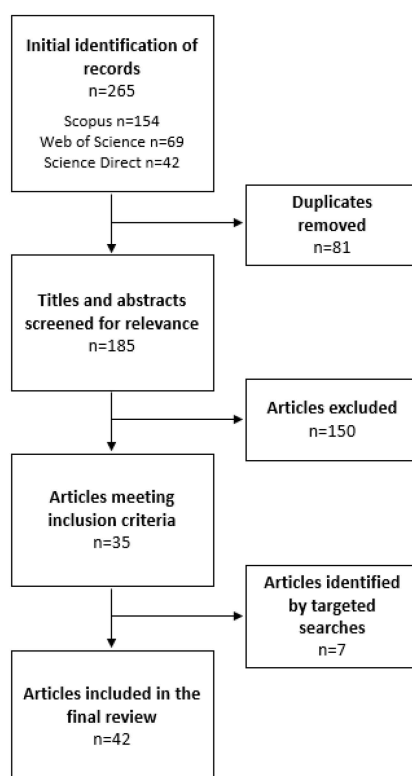


Figure 3. The literature search process and the inclusion/exclusion process for selecting publications focusing on life cycle-based approaches in the catering sector.

Since the terminology related to the food sector varies slightly in the English-speaking world, the following variations in search terms were used to capture all peer-reviewed articles that may be relevant. As mentioned in the introduction, in the USA, the term foodservice (US) refers to the industry that gives the serviced provision of meals purchased outside of home, while in the UK, this industry is more commonly referred to as the catering sector, and sometimes the term food service is also used. Therefore, all three search terms were used. The following search strategy was used to identify peer-reviewed journal articles on the application of life cycle-based approaches in the catering sector: Title, abstract, keywords: (“catering” OR “food service” OR “foodservice”) AND (“life cycle” OR “LCA”).

Search results were limited to published peer-reviewed journal articles that were written in English language. After removing duplicates, the above search string identified 185 peer-reviewed papers, which were assessed for relevance based on their titles, keywords and abstracts. The search string picked up some irrelevant articles examining topics not related to food or food services. These were mainly articles on catering theory of dividends, one of the theories of dividends in finance, and articles in which catering was used as a phrasal verb in the abstract. The following inclusion criteria were used to screen the abstracts and the full text of the remainder of the articles.

1. At least one life cycle-based intervention is used to assess the sustainability of any part of the catering supply chain;
2. The life cycle-based intervention is related to the food service sector, and does not target other segments of the food sector. LCA on food products and food groups were excluded;
3. Full text is available with sufficient information on data and methodology such as information on system boundaries, functional unit and impact categories.

In total, 35 articles met all the inclusion criteria and these were selected for the final review. Targeted searches were then conducted to expand the search and to ensure the search results were as comprehensive as possible. The following terms “life cycle” or “LCA” with “canteen”, “restaurant”, “lunch” and “dinner” were combined as follows: Title, abstract, keywords: (“life cycle” OR “LCA”) AND (“canteen” OR “restaurant” OR “lunch” OR “dinner”).

These terms were selected because lunch and dinner are the most commonly eaten meals away from home, while quick-service and casual restaurants are the most favoured eating establishments [24,25]. In addition, snowball searching methods (e.g., pursuing references of papers that met the inclusion criteria and electronic citation tracking) were used to check that much of the core literature had been captured by the search strategy and the targeted searches. These additional searches yielded seven additional papers, resulting in a selection of a total of 42 papers for the final review. The same inclusion criteria mentioned above were used for selecting papers identified by the additional targeted searches.

This review is the result of a structured analysis and synthesis of the key themes and different applications of life cycle-based approaches in the catering sector. For each paper, a pre-determined data extraction form was used to facilitate the extraction of relevant information. For each paper the following information was recorded:

1. Reference: Author(s) and publication year
2. Type of life cycle-based intervention (e.g., life cycle assessment, life cycle costing, carbon footprint, etc.)
3. The part of the catering supply chain which the intervention is targeting (e.g., production, processing, distribution, storage, preparation, consumption and/or waste management)
4. Population focus: Type of catering establishment studied
5. Geographical region of the case study or intervention(s)
6. Methodological approach: System boundaries, functional units and impact categories used
7. Type of intervention(s) and improvement scenarios proposed and evaluated.
8. Food items/products analysed, if relevant.
9. Main results
10. Whether the study only focuses on environmental impacts or takes into account wider sustainability implications such as social and economic impacts, which could range from the economic analysis and costs of interventions or health and nutritional considerations of ingredients and meals, to mention but a few.

The internal validity of the studies was assessed mainly through the LCA methodology (i.e., description of goal and scope of the studies, functional units, system boundaries, availability and quality of data and transparency about limitations, assumptions and uncertainties).

Since this is a qualitative systematic review, the narrative synthesis was developed from data coding and the data extraction form. The main outcomes and results of the studies are presented in the remainder of this article. Table A1 in Appendix A gives a summary of the studies included in this systematic review, and provides information on the studies such as type of food service studied, type of life-cycle based intervention used and information on system boundaries, functional units and impact categories.

While this study was designed to be as comprehensive, well-documented and replicable as possible, it has some limitations which should be kept in mind when interpreting results and trends.

One of the main limitations of this review is that it only includes peer-reviewed articles written in English language, therefore missing any literature published in languages other than English and grey literature that sometimes can provide additional context and information to the research question. This may have led to the omission of existing literature and case studies focusing on the application of life cycle-based approaches in the catering sector. Furthermore, since the LCA methodological choices (e.g., choice of functional unit, system boundary, impact categories) adopted in each paper are slightly different, direct comparisons cannot always be made and results may not be generalised to the entire catering sector. In addition, since most of the studies are from Europe and the USA, results may not be generalizable for other countries in different parts of the world, where currently there is a lack of LCA studies related to food services. These limitations should be kept in mind when interpreting the results of this systematic review.

3. Results and Discussion

3.1. Research Trends

There is an increasing trend in the number of articles published on the application of life cycle-based approaches in the catering sector, with a major peak in publication in 2016 (see Figure 4). More than half of the studies identified by the search strategy used case studies from just three countries, Italy being the most common ($n = 11$), followed by the USA ($n = 7$) and Spain ($n = 5$) (see Figure 5). Most of the articles (three quarters) focused on case studies from Europe and the UK.

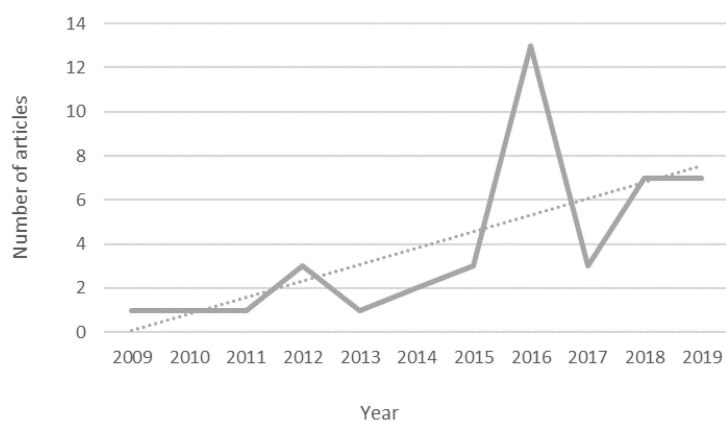


Figure 4. Cumulative number of articles published during the period 2008–2019 ($n = 42$).

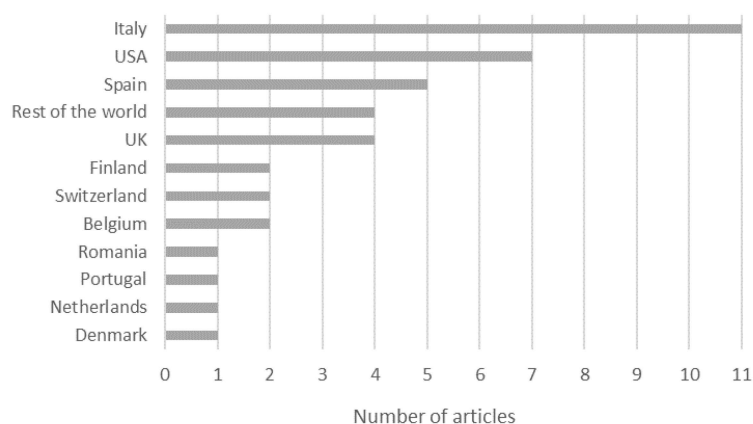


Figure 5. Geographical distribution of studies and interventions.

A range of topics was studied (see Figure 6). The most common topic was waste management in the food service sector, with 18 (43%) articles looking at the LCA of food waste and different

waste management strategies for catering. The second most common topic was the LCA of different ingredients and meals provided by various eating establishments, with just over one third of the selected papers focusing on this subject ($n = 15$). The remainder of the studies focused on the LCA of food service operations such as the various operational activities arising from the day-to-day running of a restaurant ($n = 4$), the LCA of different food production and distribution strategies ($n = 2$) and different methods of food preparation ($n = 3$). A wide range of eating establishments were studied both from the commercial and institutional segments of catering. Catering for educational institutions (e.g., nursery, primary or secondary school, $n = 10$; and university catering $n = 6$) was the most common type examined from the institutional catering segment, while from the private catering sector different types of restaurants (mainly quick-service and full service restaurants) were most frequently studied.

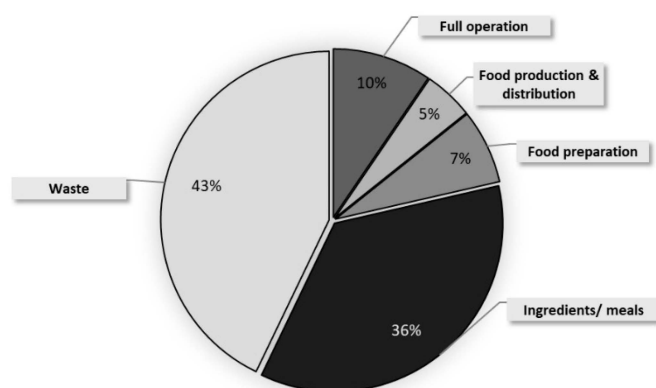


Figure 6. Themes and focus of articles ($n = 42$).

There was a wide variation in the impact categories studied across the articles (see Table A1). Despite this variation, all studies in one way or another assessed the climate change implications either through carbon footprint or using LCA and Global Warming Potential (GWP) as an impact category. Since climate change is by far one of the most pressing environmental problems we face today, it is not unexpected that GWP and the climate change impact category is the most commonly assessed impact category.

The remainder of the result section will provide an overview of the different life cycle-based approaches and interventions used to improve food service operations. Interventions are divided into high- and low-improvement potential interventions based on their effectiveness in reducing the overall negative impacts arising from catering operations.

3.2. Approaches and Interventions

In this review, numerous strategies and interventions have been identified that are available to food service businesses to improve the sustainability of their operations. By examining the full operation of catering businesses, it is possible to gain a better understanding of which of the five main stages (i.e., production, transport and distribution, storage and preparation, serving and consumption and waste management) contribute most to the impacts of catering operations. Implementing interventions targeting those stages with the highest impact will lead to the most effective way of achieving the greatest reduction of negative impacts in the whole catering operation. In this review, four studies were identified that performed an environmental assessment of the full operation of various catering businesses. All four studies [17,26–28] used LCA to calculate the full organisational environmental footprint of their chosen food service business. Baldwin et al. [26] and Mistretta et al. [17] focused on the environmental sustainability of the catering operations and thus examined a wide range of impact categories, while the rest of the studies [27,28] mainly focused on global warming potential. One common conclusion was that interventions addressing the food production phase have the greatest potential to reduce the overall environmental impact of catering operations.

Baldwin et al. [26] estimated the relative contribution of each stage (procurement, storage, preparation, food service) to the total environmental impacts and found that food procurement was the largest source of environmental impacts and the leading source of land use (97%), respiratory inorganics (84%), acidification/eutrophication (65%) and climate change (53%). On the other hand, food storage, food preparation and cooking did not contribute significantly to the impact categories. Mistretta et al. [17] also found that the food production phase contributed more than 65% to almost all the environmental impacts examined (global warming, acidification, eutrophication and global energy requirement), with the exception of photochemical oxidation, where the largest impact was linked to the transportation phase.

When only examining the climate impact, Mistretta et al. [17] found that the production phase had the greatest impact (69%), while transport, storage, cooking and tableware production were responsible for about 6%, 10%, 7% and 8%, respectively. The contribution of waste treatment was negligible (lower than 0.4%) in all the impact categories examined. Jungbluth et al. [28] came to similar conclusions, with an estimation of the impact from food procurement to be approximately four times higher than the direct impacts arising from the operation of the catering facility. The results of Cerutti et al. [27] showed that the production phase was the phase with the most impact (78% of the carbon footprint of the full service), while other phases had much lower contributions (food logistics 3%, food preparation 8% and waste 11% of the total carbon footprint of the service).

Based on the results summarised in Table 1, interventions targeting different stages of the catering supply chain can be divided into two categories: High- and low-improvement potential interventions. While the system boundaries of the above mentioned studies vary slightly, and therefore direct comparisons are difficult to make across the four studies, it is still evident that the production phase has by far the greatest impact (ranging from 58% to 78%, see Table 1), contributing the most to not only climate change but also to other impact categories. Reducing the negative impacts arising from the production (and procurement) phase is therefore a priority area for action and interventions targeting this phase can be considered high-improvement potential interventions. In the following section, some of the most common high-improvement potential strategies such as changing menus and sourcing ingredients with higher production standards will be examined. Their effectiveness in reducing the impacts from the production phase and thus the overall impact of catering services will be evaluated. The second half of the paper will present further interventions identified in this review that target the phases of transport, food storage, meal preparation and serving and waste management. These low-improvement potential interventions are also important because they can further reduce the negative impacts of catering operations.

Table 1. Relative contribution of each stage to the overall impacts of catering services. * Results presented in the table correspond to the climate change impact category only.

Reference	Food Production	Transport and Distribution	Storage and Preparation	Serving and Consumption	Waste Management
[17] *	69% (plus 8% from tableware production)	6%	10%	7%	0.4
[26]	94.7% (food production & transport combined)		1.9%	3.4%	-
[27] *	78%	3%	8% (preparation and consumption combined)		11%
[28] *	58% (plus 12% from processing & packaging)	6%	24% (preparation, serving and waste combined)		

3.3. High-Improvement Potential Interventions

3.3.1. Reducing Impacts from Food Production

In the literature, two fundamental ways were identified in which the negative impacts from the food production phase can be reduced by catering. Both of these interventions can be achieved

through food procurement, a term that simply refers to the purchase of ingredients and food. The first strategy is to prioritise the purchase of food items produced with higher environmental production standards. While, the second strategy is to (re)design menus and offers in a way that they are no longer centred around high-impact ingredients (e.g., animal products) but instead make use of the diversity of low-impact ingredients (e.g., plant foods).

Which, however, of these two strategies, if any, should be prioritised? Moreover, are interventions focusing on food sourcing with higher environmental production standards more effective than changing menus or vice versa? By using LCA it is possible to quantify and get an estimate of the potential impact reduction achieved by these strategies addressing the production phase. In this review, one study [27] examined the climate change reduction potential of 12 procurement policies, and ranked these based on their potential to reduce GHG emissions (see the top three in Table 2). According to the results, the replacement of meat-based meals with vegetarian meals was the most effective intervention, resulting in a 32% reduction of the overall carbon footprint of the catering service (see further details on the impact of changing ingredients/menus in Section 3.3.2). The adoption of improved production practices (i.e., purchasing organic food solely) was the second most effective intervention, leading to further reduction of 11% of the whole catering service (see further details in Section 3.3.3). Changing the provision of food from international markets to regional markets resulted only in a 0.2% overall carbon footprint reduction, suggesting that purchasing local food, something that is often regarded as an “environmentally sustainable practice” may not be the most effective way of reducing GHG emissions from catering operations. Changing menus on the other hand seems to be the most effective way of reducing impacts from the production phase, followed by purchasing food with higher environmental production standards (i.e., organic).

Table 2. The ranking of three interventions targeting the production phase according to their overall carbon footprint reduction potential based on the study of Cerutti et al. [27].

Intervention	Overall Reduction	Strategy
Replacing meat-based meals with vegetarian meals	32%	Changing menus
Adopting improved production practices (organic, integrated production)	11%	Changing the sourcing of food
Changing geographical origin of food (from international to regional market)	0.2%	Changing the sourcing of food

It is important to note that studies adopting an LCA approach can only analyse specific case studies, and therefore results are inherently context specific. Subsequently, further research confirming these trends in different catering contexts would be beneficial. The environmental benefits of changing ingredients/menus are quite well established (see details in Section 3.3.2); however, further research on the performance of different production methods in different contexts would be useful, especially because of the high sensitivity of LCA results to yields, which is in turn influenced by factors such as type of food grown, plant variety, geographical location, soil and climate conditions etc. [29]. Furthermore, policies addressing the geographical origin of food may have different improvement potentials in countries which do not have a climate suited to growing fruits and vegetables, and are therefore more reliant on importing these commodities. Additional research verifying these findings and examining different geographical contexts would be beneficial, especially if other impact categories besides climate impact were to be included in future assessments.

3.3.2. Meals

As highlighted above, changing ingredients and menus is one of the most effective strategies that food service businesses can adopt to reduce their overall environmental impact. With the help of life cycle-based tools, the impact of different types of ingredients and/or meals can be assessed, and catering offers can be strategically changed so that the negative impacts arising from different types of

ingredients/meals can be mitigated or eliminated, bringing improvement to the entire supply chain from food production, procurement to food consumption and waste management.

In the literature, two main LCA approaches were identified to assess the environmental impacts arising from food service offers. The first approach is a hotspot analysis of ingredients, in which the contribution of different ingredients in a meal to the total environmental impacts is estimated. Studies adopting this approach [30–32] used ingredients on a mass/weight basis as the functional unit. Such a functional unit is sufficient for identifying hotspots within a system; however, when the aim is to evaluate different food types that have different nutritional roles, an alternative functional unit is needed [33]. Nevertheless, focusing on ingredients can be useful when the aim is solely to identify which ingredients have the highest contribution. A common finding of the LCA studies focusing on ingredient hotspot analysis is that red meat, especially beef, has the highest environmental impact according to the functional unit of a kilogram of food product and is leading impact on ecological footprint [30] and cumulative energy demand [31]. With regards to GWP, findings of Wickramasinghe et al. [32] suggest that the contribution of meat and fish has the largest share of GHG emissions.

The second approach focuses on the assessment of the environmental impact of entire meals instead of individual ingredients. Studies adopting this approach tend to use either the functional unit of an average meal [34–41] or a given quantity of prepared product (ready meal) [42–44], instead of using a mass based functional unit of ingredients. Regardless of the choice of functional unit, these studies usually compare the environmental impact of different types of meals (e.g., meat-based meals vs. vegetarian meals). A common finding among studies is that vegetarian meals have considerably lower environmental impact than meat-based meals [34,36–38,44,45]. Saarinen et al. [37], for example, found that meat-based lunches have two to three times greater climate impact, and four to five times greater eutrophication impact than vegetarian meals. Saxe et al. [44] found that main meals with beef have 8–11 times higher environmental impact than an average vegetarian meal. However, other studies [34,36] highlighted that even though vegetarian meals tend to have the lowest impact in general, certain types of vegetarian meals (i.e., those rich in animal-based ingredients such as dairy) had an environmental impact as high as average meat-based meals (e.g., meals with chicken, for example, [34]). Such findings highlight issues with the definitions of meals used in LCA studies. It is evident that no clear distinction has so far been made in LCA studies focusing on meals between various types of plant-based meals, and to date most meals that do not contain meat are grouped into the “vegetarian” category. A few studies, e.g., [36,37] made reference to vegan meals in their research; however, normally they were mentioned in the same category as vegetarian meals, disregarding key differences between not just these two terms, but also between their environmental impacts. Such choices have especially important implications for the results of LCA of meals. First and foremost, due to the lack of distinction between different types of plant-based meals in LCA studies, vegetarian meals in many cases do not show a considerable difference compared with other menu options such as poultry or pork [38] or fish and seafood [44]. In addition, lumping all types of plant-based meals under the term “vegetarian” can prevent us from finding out which types of meals are truly the most environmentally sustainable.

Despite the lack of consistent terminology used in LCA studies, meals made with no or low amount of animal-based ingredients (e.g., vegetable soups, curries and tofu, bean and lentil dishes [36]) have the lowest environmental impact and thus are the most (environmentally) sustainable. This is mainly because the production of animal-based foods (whether it is meat, dairy or eggs) is more resource-intensive and environmentally impactful than the production of plant-based foods [46,47]. Consequently, changing menus and reducing meat consumption by replacing animal products with plant-based ingredients is an effective way of reducing the environmental impact of not just meals but also the overall environmental impact of catering operations as demonstrated by Mistretta et al. [17] and Cerutti et al. [27]. In addition, this intervention would also have important social sustainability benefits, mainly in the form of improved public health, which is discussed in the following section.

While LCA is a well-established tool for assessing the environmental impacts of meals, inclusion of nutrition in LCA of meals is less common, and methodologies for comprehensive nutritional and health assessment are lacking [48]. Omitting health and comprehensive nutritional assessment of meals in LCA studies may lead to recommendations and menu design that is only informed by environmental sustainability and overlooks the nutritional and health impacts associated with the consumption of different types of food items and meals.

In this review, less than two thirds of studies that focused on the LCA of meals and ingredients carried out some kind of health and/or nutritional assessment as part of their LCA. Most of them assessed the nutritional quality of meals either by (a) using individual parameters such as energy intake (i.e., calories) or intakes of specific macronutrients (e.g., protein, fat, carbohydrates, see, e.g., [39,48]) or (b) using multiple parameters such as the combination of macro- and micronutrients (e.g., fat, protein, fibre, calcium, iron and/or different vitamins, e.g., [32,43]). Analysing the macro- and micro-nutrient content of meals can provide information about the nutritional quality of meals and how nutritionally complete they are; however, that is not necessarily a measure of how healthy they are, as nutrients can be obtained from various sources—some of which are healthier than others. Further research on the development of more comprehensive health and nutritional criteria, in which the source of nutrients (e.g., animal vs. plant sources; unprocessed whole foods vs. processed and ultra-processed foods fortified with synthetic vitamins and minerals [49]) is also taken into account, would therefore be useful.

When examining the methodological approaches adopted by studies in this review using nutritional assessment of meals within LCA, two approaches can be distinguished. In the first approach, the nutritional assessment is used to compliment the LCA, while in the second approach the nutritional assessment is integrated into the LCA. The first approach, which is widely adopted by studies [32,39,40,43,48], is based on the idea that environmental sustainability assessment and nutritional assessment are two separate tools and hence no single outcome can be obtained. The advantage of this approach is that it is relatively simple and the results, especially for nutritional scoring, can be easily understood and interpreted by catering staff and customers. However, it does not allow for direct comparison of meals based on their nutrient/health profile in relation to their environmental impacts. On the other hand, the second approach, which aims to integrate nutritional assessment into LCA by using various nutrition-based functional units, addresses this problem. However, it is more complex and therefore to date, only a handful of studies in the catering sector have adopted this approach, e.g., [34,37].

Despite the methodological differences in the assessment of nutritional and/or health impact of meals, results show that meals with low environmental impact also tend to be healthier as they contain lower amounts of protein and fats from animal products that are associated with higher risks of disease, while containing higher amounts of fibre [40,42] and phytonutrients. However, meals with lower environmental impact (e.g., vegetarian and even some vegan meals) can sometimes conflict with their healthiness [41]. To address this issue, a shift in terminologies such as the one recommended by Tusó et al. [50] may be helpful. Instead of focusing on terms like vegetarian or vegan, the emphasis is suggested to be on the consumption of unrefined whole foods of plant origins (i.e., fruits and vegetables, nuts, seeds, herbs and spices, legumes, wholegrains etc.). As such, distinguishing between animal-based meals (i.e., meat-based and vegetarian meals) and whole food, plant-based meals (which include vegan meals but exclude processed vegan meals, for example) might generate more consistent results across LCA studies both in terms of environmental and health impacts. To date, only van de Kamp and Temme [42] attempted to use similar distinctions to compare the impact of different types of catered meals. Their findings suggest that plant-based meals have the potential to improve nutrient intake and tastiness while reducing environmental impacts.

It is evident that replacing animal-based ingredients in menus with plant-based ingredients could make a significant contribution towards improving the environmental sustainability of meals and catering operations. Robust scientific evidence also suggests that lowering the average consumption of animal-based products while increasing the average consumption of fruits, vegetables and whole

grains can not only provide environmental benefits but also health benefits [8,51,52]. Consequently, future research regarding the LCA of meals could benefit from a more accurate classification of meals (i.e., distinguishing between plant- vs. animal-based meals as mentioned above). In addition, the integration of comprehensive health and nutritional assessment of meals within LCA would also be beneficial so that both the environmental and health impacts of different types of meals can be better understood.

3.3.3. Production Systems

The second most effective strategy identified in this review for reducing the impacts from the production phase was adopting improved production practices. Cerutti et al. [53] assessed the climate change reduction potential of procurement policies of different food production methods (conventional, integrated and organic production) using LCA. They found that conventional production practices had higher GHG emission than organic and integrated production practices. The lowest GHG emission per unit of production was for integrated production, mainly due to the increased productivity of the integrated system when compared with the organic system. Baldwin et al. [26] also found reduction in environmental impacts when replacing 25% of total food purchases with organic alternatives. Caputo et al. [54] also found that a gradual change from conventional agriculture to integrated and organic agriculture had great improvement potential for reducing Cumulative Energy Demand of the catering service. These results suggest that integrated and organic production systems should be preferred over conventional high input/high output systems. Overall, organic and integrated production can reduce GHG emissions by as much as 32% of the production phase, when compared with conventional production methods [27].

Besides environmental reasons, preferring organic over conventional production systems may also have positive (public) health outcomes, a matter normally not considered in LCA studies. Organic foods naturally have lower pesticide residue than conventionally produced foods. Consequently, the consumption of organic foods clearly provides protection against pesticides that are commonly used in conventional agriculture both in children [55] and adults [56]. The negative health effects of pesticide residues and elevated rate of chronic diseases are well documented in people with direct exposure to pesticides (i.e., in those living or working around pesticides such as farmers, or those working in the agricultural industry, etc.) [57]. However, robust evidence on indirect exposure to pesticides (i.e., through pesticide residues in consumers' food) is presently lacking as human observational studies examining the health effects associated with the consumption of organic compared with conventional foods have not yet been done [58,59]. Despite this, Oates [56] (p. 110) suggests that "the consumption of organic food provides a logical precautionary approach to reducing pesticide exposure" which in turn could potentially help avoid various health impairments from pesticide exposure.

As already mentioned in Section 3.3.1, due to some of the drawbacks of organic farming (mainly lower yields and nutrient losses [60]), further research on the environmental performance of different farming systems through LCA, such as the study done by Nemeček et al. [60] for Switzerland, and how the weak points of organic system could be addressed, would be beneficial so that the catering sector, as well as governments and policy makers who design buying standards for food and catering services, could make more informed decisions on food purchasing and procurement.

3.4. Low-Improvement Potential Interventions

So far, some of the most important high-improvement potential interventions such as changing menus and sourcing ingredients with higher environmental production standards have been reviewed. These interventions directly address the food production phase, which is the phase with the greatest impacts, and thus are the most effective in reducing the overall impact of catering operations.

Interventions addressing other stages (i.e., food storage, preparation and waste management) also help improve the full operation of catering services and reduce negative impacts to a certain degree; however, they are not classified as high-improvement potential interventions as they are only capable

of achieving a slight overall reduction in impacts (see Table 1). In the following sections, interventions addressing the stages of food preparation and waste management will be discussed.

3.4.1. Food Preparation

There are two main approaches generally used for the preparation of food in catering. The first approach is the cook–serve approach used by most restaurants and canteens. In this approach, once food is prepared, it is immediately served to customers and thus all stages of food preparation happen within a few hours of the food being served and consumed. In contrast, in the deferred system a considerable amount of time, ranging from several hours to days and even months—depending on the preservation method used—can pass between the preparation of food and the actual consumption of it [16,61]. Certain types of catering (e.g., hospitals, schools, catering for events and festivals) take advantage of different types of deferred catering (e.g., cook-warm, cook-chill and cook-freeze) as it allows them to prepare food at times and places different from consumptions [16,61,62]. In this review, only one study [16] was identified that compared the impacts from cook-warm and cook-chill systems in catering using pasta as a case study. Results showed that the cook-warm system is more environmentally sustainable than the cook-chill system, having 17% lower fossil depletion, 30% lower freshwater eutrophication and 96% lower ozone depletion impact. Therefore, this approach should be prioritised over the cook-chill system whenever possible. However, the choice of preparation approach used by catering depends on many other factors such as cost, flexibility, efficiency, food quality and convenience, which were not addressed in the study of Fusi et al. [16]. Consequently, there is scope for future research examining the role of these factors and how the sustainability of both cook-warm and cook-chill systems could be improved. Furthermore, examining the environmental impacts associated with the most common preparation approach used in catering (cook–serve) using LCA would also be useful to get a more comprehensive understanding of how different food preparation approaches used in catering compare with each other.

Fusi et al. [16] also carried out an LCA-based comparison of different cooking technologies used for pasta cooking. Cooking in pasta cookers can save up to 60% of energy and 38% of water compared to range tops, reducing impacts arising from pasta preparation by 34 to 66 percent. Whether electric, gas or liquefied petroleum gas pasta cookers yield the lowest environmental impact depends on the actual energy and electricity mix of the particular country under examination. If a significant share of the electricity mix comes from coal and oil, pasta cookers using natural gas are the best while electric cookers are the worst from an environmental perspective [16].

Mudie and Vadhati [21] assessed the carbon and energy impacts of different food preparation options and found that many appliances in commercial kitchens of food service facilities are over specified (e.g., steamers, combi ovens) and as a result underutilised. Replacing fryers, grills and microwave combi ovens with steam combi ovens and reducing demand for freezing was found to lead to significant energy savings (58%) as well as cost savings [21]. While these results are case study specific, moving away from the use of energy profligate and costly appliances in commercial kitchens should be something to be considered by catering operations. This can be done in a number of different ways depending on the catering facility, e.g., though the adjustment of menu and cooking methods, or by replacing appliances. Further research investigating the preparation of other types of food using different appliances and cooking methods, e.g., steaming, frying may be something to consider in future research as this can provide additional insights on which types of cooking technologies have the lowest environmental impact. Cooking methods also have an impact on the nutrient content of food and thus the healthiness of meals [63], and therefore these impacts should also be taken into account when designing menus and choosing food preparation methods.

3.4.2. Waste Management

As discussed earlier, interventions targeting waste management can be classified as low-improvement potential interventions since the relative contribution of waste management to the

overall impacts of catering services is only between 0.4 and 11 percent. Despite this, nearly half of the papers in this review focused on interventions addressing waste. This section will provide an overview on how life cycle-based interventions can facilitate choosing optimal waste management strategies for different types of waste produced by the catering sector.

Solid organic waste (mostly food waste) represents unnecessary losses of resources that were once used in the production, transport, storage and preparation of food. Beretta and Hellweg [64] estimates avoidable food waste at 108 g/meal, which corresponds to 238 g CO₂-eq/meal avoidable emissions. This is a relatively small contribution to the total GWP of meals, which ranges between 1.4 kg CO₂-eq/meal [17], 1.6 kg CO₂-eq/meal [27] and 4.1 kg CO₂-eq/meal [28], nevertheless it is a completely unnecessary source of emission.

Cristóbal et al. [65] highlighted the importance of setting environmental impact reduction targets instead of food waste reduction targets (simply defined by the amount of food waste) for the implementation of effective food waste prevention measures. When taking into account the embodied resource consumption of different types of food waste using LCA, it becomes evident that although meat-based food items are the least wasted food category by weight, they have the largest embodied GHG emissions in both pre- and post-consumer stages. On the other hand, fruits and vegetables followed by grains are the largest sources of food waste by weight, yet such waste has much lower embodied environmental impacts [66]. Strategies aimed at the reduction of food waste from fruits, vegetables and grains (i.e., the largest sources of food waste by weight) will lead to large quantities of food waste being diverted from the waste stream and landfill, reducing disposal and landfill costs for catering facilities. However, if the aim is to maximise the reduction of GHG emissions, as opposed to simply reducing the quantity of waste and its disposal costs, then food waste from food categories with high environmental intensity and embodied emissions (e.g., meat, cocoa, vanilla, imported products by air freight, etc.) should be prioritised [64].

This information should be taken into account when developing solutions to the common production planning problems faced by many types of catering establishments (e.g., institutional catering or all-you-can-eat establishments). In the presence of uncertain demand, catering businesses constantly have to balance overproduction costs and shortfall costs. Generally, only the financial costs associated with these activities are considered. However, when overproduced food is discarded, not only edible food is thrown away but resources that were used throughout the entire life cycle are also wasted. By using data from LCA, such as embodied GHG emissions in different food items, environmental costs associated with each wasted food item can be estimated. When environmental costs of overproduction are added to the disposal costs, optimal production levels decrease significantly for food items with high environmental impacts, while decrease by a relatively small amount for food items with less embodied CO₂ [67]. Accordingly, the overproduction of high-environmental-cost items should be avoided. In cases where demand is uncertain and the aim is to minimise the risk of shortfall, plant-based foods should be prepared as extra portions, since less GHG emissions are associated with the wastage of low environmental cost meals [66]. In the case of overproduction, food waste prevention measures such as food redistribution schemes can still be implemented to avoid wasting over-produced plant-based meals and its embodied resources.

Despite every effort, it is not possible to completely avoid all food waste as there are certain amounts of unavoidable waste in the catering sector (e.g., vegetable peelings, leftovers, food spoilage etc.), both at pre- and post-consumption. Therefore, the evaluation of the environmental performance of different solid waste management systems using LCA in the food service context is also needed. While reviews exist on this topic, e.g., [68,69], the performance of solid waste management systems in the food service context is less known. Since the composition of waste generated by the catering sector can be quite different from that of other sectors, it is important to identify which waste management strategies may be the most optimal for food service operations.

Studies in this review overall agree that diverting food waste from landfills is always favourable as landfills have worse overall environmental performance than alternative solid waste management

systems [70–73]. Implementing on-site waste to energy systems can be beneficial for catering facilities, and are preferred over landfill disposal in terms of financial costs, energy and GHG emissions [70]. Anaerobic digestion tends to outperform composting due to electricity offsets from anaerobic digestion; however, this depends on GHG intensity of electricity generation [71]. Whether food waste should be diverted to composting, anaerobic digestion or other waste-to-energy technologies depends on the local context, food waste characteristics of the particular catering establishment, site-specific performance and the GHG intensity of the electricity grid, to mention but a few factors [71,74]. Therefore, it is difficult to say which waste management strategy is the most desirable for catering in general to dispose unavoidable food waste. In addition to large scale centralised waste management options, innovative small-scale decentralised waste management solutions, such as the one described by Yeo et al. [75] using fermentative microorganisms, are also emerging as possible solution for organic food waste treatment. Depending on the context, decentralised solutions could also be a viable and sustainable food waste treatment option for catering. Based on the results of the studies included in this review, a summary of food waste management strategies for catering can be found in Figure 7.

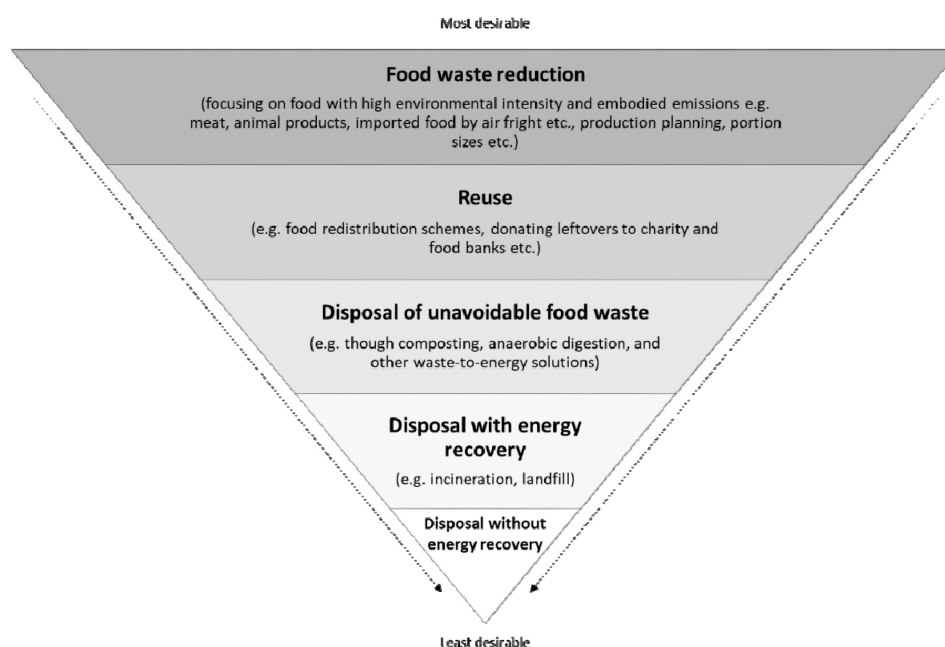


Figure 7. Summary of food waste management strategies for catering from most desirable (top) to least desirable (bottom).

Knowing the economic performance of different waste management systems alongside their environmental performance can further help decision-making. In this review, only two studies evaluated the economic implications of different waste management options. Franchetti [70] used internal rate of return (IRR) and payback period to compliment the LCA of different types of anaerobic digestion of organic waste to energy technologies. While Escobar et al. [76] used a more holistic life cycle approach and examined both the environmental [77] as well as the economic performance [76] of an integrated system for the management of both solid and liquid organic waste from catering using LCA and Life Cycle Costing (LCC), respectively. Results showed that oftentimes there are possible trade-offs between environmental and financial outcomes. Escobar et al. [76] found that switching to the proposed waste management system would have substantial environmental savings in most impact categories; however, this would be at the expense of profits generated. While combined life cycle approaches capable of examining both the environmental and the direct monetary costs are not currently widespread, they would nonetheless be useful for helping the catering sector make more informed decisions regarding the environmental and economic outcomes of not only waste management options but also other interventions.

In addition, another promising area for future research could be the evaluation, using life cycle approaches, of the effect of the adoption of modern technologies, such as food irradiation, that are used frequently nowadays to destroy food borne pathogens and extend the shelf life of foods (e.g., fresh fruits and vegetables, cereals, aromatic herbs and spices, etc.). The benefits of irradiation technology (i.e., slowing down the ripening process of fruits and vegetables, prolonging shelf life and reducing pathogens) can not only ensure the health and safety of consumers [78] but could also potentially benefit the food service sector as it could help reducing food waste arising from the spoilage of fresh ingredients.

Most catering facilities not only have to deal with the management of solid but also liquid organic waste. Waste cooking oil (WCO) is a major waste product of cooking and preparation processes for many catering establishments, which normally has to be collected by authorised companies. From this review, it has become evident that an efficient and cost-effective strategy to deal with WCO from the catering sector is to recycle it and produce biodiesel from it [79,80]. Caldeira et al. [79] found that biodiesel derived from WCO has considerably lower environmental impacts than biodiesel produced from virgin feedstock or fossil diesel. While the amount of WCO from the catering sector only allows for a small percentage of diesel to be substituted by WCO biodiesel, it does contribute to the replacement non-renewable fuels [79], while avoiding the inappropriate disposal of WCO [81]. With efficient WCO collection systems [79,81] and high WCO recovery ratio [79], more sustainable and cost-effective management of WCO could be achieved, which would be mutually beneficial for both catering operators and biodiesel producers. From these studies, it can be concluded that recycling WCO from catering operations and turning it into second-generation biodiesel is better from an environmental and economic sustainability standpoint than depositing it. However, to date no studies have examined the potential benefits of avoiding the generation of WCO in the first place by reducing the amount of cooking oil used in meal preparation. On the one hand, this approach may reduce the amount of WCO available for biodiesel production; however, on the other hand, it would have a positive impact on public health, since oil used for deep-frying is associated with adverse health effects, especially affecting endothelial function [82].

Packaging is often regarded as a standard and integral part of handling and transportation of food and ingredients to protect and preserve the physical and nutritional qualities of food [83]. Consequently, the food service sector often has to deal with large quantities of packaging and other disposables. In this review, only one study [84] was identified which quantified both the economic returns and environmental impact of different packaging systems in the catering sector. Accorsi et al. [84] found that when comparing multi-use system of reusable plastic containers to traditional single-use packaging (e.g., wooden boxes, disposable plastic crates and cardboard boxes), the multi-use system had lower environmental impact in terms of CO₂-eq emissions than single-use packaging. However, the costs associated with multi-use packaging were higher, with an increase of approximately 0.06€ per kilogram of handled food product. Certain parameters (e.g., life span of multi-use packaging, materials used for the production of packaging, end-of-life disposal) can significantly affect both the environmental and economic analysis [84], therefore, further studies would be useful to examine ways in which multi-use systems can be designed so that they not only have lower environmental impact, but also cost less than traditional single use packaging. This information would be valuable for distributors more than for the catering sector as catering outlets generally do not have much say in how food and ingredients (along with other non-food items) are distributed and delivered. Nevertheless, catering facilities may intentionally choose distributors who use packing options with lower environmental impact. This would benefit catering facilities financially as they can save costs associated with the disposal of single use packaging by using multi-use packaging systems and thus preventing waste from packaging. Since no other LCA studies were found on different packaging options used in catering, further research on this topic would be useful.

Single use tableware and cutlery are another waste source that certain types of catering facilities such as quick-service, fast food establishments, contract catering etc. have to manage. In this review, two studies examined the environmental performance of biodegradable and compostable cutlery [85]

and tableware [86]. From an environmental life cycle point of view, they both perform significantly better than single use plastic alternatives. In fact, Fieschi and Pretato [86] found that the greatest opportunity of replacing cutlery and tableware does not lie in the substitution itself, but in how the type of cutlery and tableware can influence the final waste treatment strategy adopted by catering facilities. Biodegradable and compostable cutlery and tableware can be disposed in the same way as organic food and kitchen waste (e.g., through organic recycling methods), whereas traditional tableware from fossil fuels is incompatible with organic waste recycling and thus has to be either disposed in landfills or incinerated. Therefore, shifting from the generation of mixed heterogeneous waste to mixed homogeneous waste (containing both the food waste and compostable tableware) while adopting organic recycling strategy to the homogeneous waste is a preferred waste management strategy for single use cutlery and tableware used by many catering facilities [85,86]. It is important to note that this only holds true if the tableware is disposed within the premises of the catering establishments where organic recycling of the tableware happens along with food waste. However, oftentimes food is taken away and consumed outside the premises of catering outlets resulting in the food waste and the tableware (even if it is biodegradable) being disposed in the garbage instead, and thus the benefits from organic recycling are not harnessed. No other studies were identified in this review that looked at other types of tableware and cutlery, whether reusable or disposable, used in the catering sector, therefore further LCA studies on this topic could be conducted.

3.5. Implementation of Interventions

This review so far has summarised and discussed some of the most important interventions, categorised according to their effectiveness in reducing environmental impacts, available to food service establishments to improve the environmental sustainability of their operations, while also considering some important social and economic sustainability concerns. However, to best support the sustainability transition of the food service sector, it is also important to assess the effectiveness of interventions in relation to the effort required to implement them. As shown in Figure 8, interventions aimed at the production phase and procurement have the greatest improvement potential. However, the implementation of these strategies is not always easy and straightforward as it involves processes upstream and downstream of the actual operation of catering facilities. The success of the implementation of the intervention with the highest improvement potential that target dietary shift, for example, is greatly dependent on the attractiveness of the alternative meals offered, customer perception and the ability to overcome stable habits of food consumption that tend to be resistant to change without any external influence and support. Pricing, nudging, communication of both the environmental and health benefits of such offers through various mediums are just a few mechanisms that can be used by catering to overcome resistance to change and facilitate the uptake of healthier and more environmentally sustainable offers [87,88]. Using labelling schemes such as “climate-friendly” label is suggested as an effective way of increasing the number of climate-friendly meal purchases. Visschers and Siegrist [41] found that such labelling scheme increased the number of climate-friendly meal purchases, but did not affect customer satisfaction, which is extremely important to most food service providers.

On the other hand, interventions targeting food waste reduction and waste management have low improvement potential, but are relatively easy to implement. Food service businesses can achieve substantial food waste reduction within just a few weeks or months merely by implementing simple preventive measures such as serving smaller portions, optimising planning systems, donating leftovers and training staff. Beretta and Hellweg [64] found that on average such interventions can achieve 38% food waste reduction, which corresponds to 41% reduction in the climate impacts of food waste and 30% in the biodiversity impacts. Food waste prevention measures may also create potential financial savings for food service businesses, mainly as a result of food cost savings, reduced total food purchases [64] and cost savings of labour, electricity, water, cleaning products and taxes [35]. However, despite the environmental and potential economic benefits, prevention measures may not always be prioritised by catering management, especially if a type of reuse, recycle or recovery measure is

more cost-effective in the short run than the prevention measures [65]. Nevertheless, LCA, especially if accompanied with economic assessment, can be useful for identifying “quick win” prevention measures where environmental impacts can be avoided at a low cost (e.g., smaller plates, trayless dining and consumer education campaigns) [65].

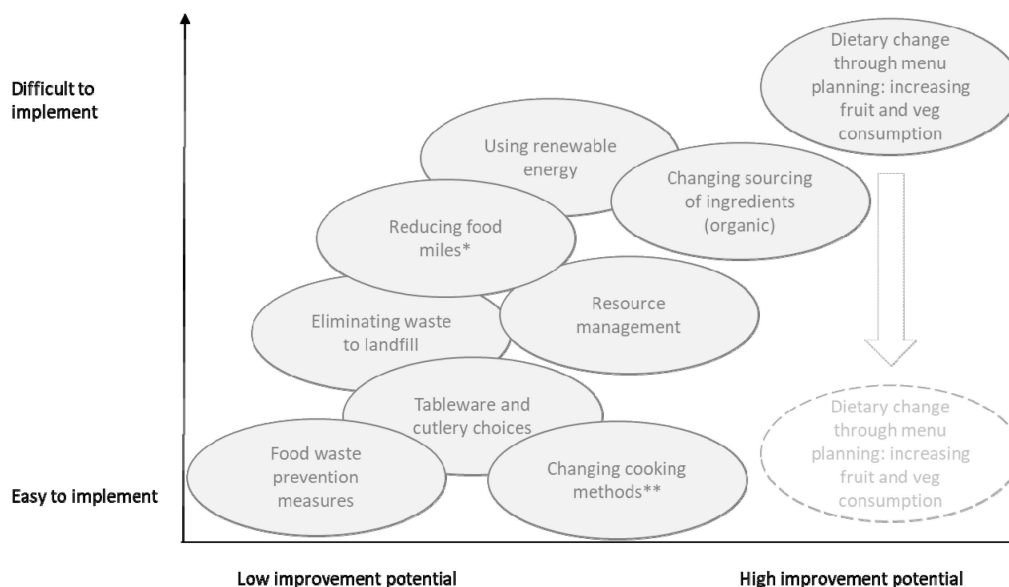


Figure 8. Interventions categorised according to improvement potential and the difficulty of implementations. * Reducing food miles is highly context specific, and depending on the country it can be an easy to implement intervention (e.g., in Italy), or a difficult to implement intervention in countries where climate conditions make imports of fruits and vegetables necessary. ** Changing cooking methods are classified as low improvement potential interventions; however, when also taking into account the considerable health benefits these interventions could bring (i.e., replacing deep-frying methods), the overall sustainability improvement potential may increase.

Since high-improvement potential interventions (e.g., dietary change, increasing fruit and vegetable intake and changing the sourcing of ingredients) are currently more difficult to implement than low-improvement potential interventions, they may not always be the preferred interventions chosen by catering services, despite the significant improvement these changes can bring. Lack of internal resources (i.e., necessary finances, expertise, labour and time), inconstant customer demand and organisational and operational complexities are some of the key barriers that need to be overcome [89].

While not directly related to LCA research, further research and insights on how to make “difficult-to-implement” strategies more appealing from a social, environmental, economic and operational point of view, would nevertheless be useful and could complement existing LCA research. This would help shift interventions from the top right corner in Figure 8 (high-improvement potential, difficult-to-implement) to the bottom right corner (high-improvement potential, easy-to-implement) as indicated by the dashed arrow.

4. Conclusions

In this review various life-cycle based interventions and their effectiveness in improving the sustainability of catering supply chains have been examined. Individually, all interventions performed better than the baseline or business as usual scenarios, and thus they all contribute to improving the sustainability of food service operations to various degrees. However, one of the main findings of this review is that interventions do not have the same effectiveness and ability to reduce the overall impacts from catering operations. Life cycle-based tools therefore prove to be useful for not only identifying hotspots for impact reduction in the catering supply chain, but also for comparing the performance of

different interventions so that the most effective measures can be adopted or prioritised. Though it may be inappropriate to draw firm conclusions from the results of specific case studies for the entire catering sector, convergences and reoccurring trends across the case studies can be observed, which are briefly summarised below.

The distribution of the environmental impacts along the catering supply chain was found to be fairly similar in studies analysing the impact of the whole catering operations, e.g., [17,27,28,35]. Results of studies in this review clearly showed that the production phase is by far the largest source of environmental impacts, and therefore interventions targeting this phase have the highest improvement potential. It is also clear that shifting dietary patterns by replacing meat and animal-based ingredients with plant-based ingredients is one of the most, if not the most, powerful environmental mitigation strategy for food services. Not to mention the public health benefits associated with increased consumption of fruits, vegetables and whole plant foods, and the impact on billions of non-human animals that are currently exploited in our food system and have to bear the burden of our unsustainable eating habits every day.

Besides changing menus, the shift of food production from conventional to organic agriculture or integrated production was also found to have high-improvement potential. Other strategies aiming to enhance the efficiency of catering supply chains are also relevant. These include improving energy and water management practices in food service operations such as cooking, storage and serving, reducing losses and waste and shortening transportation distances. Even though these interventions have lower improvement potentials than those interventions targeting the production phase, they still play an important role as they can be easily implemented and can further increase the mitigation potential of this sector.

From this review, it can be concluded that life-cycle based approaches and tools prove to be useful for identifying hotspots in various stages of the catering supply chain, and can help improve the environmental performance of the whole system. However, the food service sector could benefit from the results of combined life cycle thinking approaches as these would also be capable of assessing other dimensions of sustainability such as the economic and social aspects of choices and interventions. To date such combined approaches are not widespread. As a result, future research efforts could be focused on the integration of different life cycle thinking approaches. In particular, the integration of comprehensive health and nutritional assessment of meals within LCA would be especially beneficial for meal planning as this would allow for the assessment of both the environmental and health dimensions of different menu options. Future research efforts could also focus on procurement choices and the performance of different production methods and the potential environmental as well as health impacts and benefits associated with organic, integrated and conventional production methods. Inclusion of economic analysis could also be useful as it could provide information on the financial aspects of choices and interventions. Lastly, future research and insights on how to make “difficult-to-implement” strategies identified in this review more appealing from a social, environmental, economic and operational point of view would also be useful for improving the sustainability of the food service sector. Such insights could provide further incentives for the implementation of high improvement potential interventions that currently prove to be difficult to implement, which is essential for creating a more sustainable food service sector for all.

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Appendix A

Table A1. List of the 42 studies included in the review.

Study	Topic	Geographic Location	Type of Food Service	Type of Tool Used	System Boundaries	Functional Unit	Impact Categories	ECON	SOCIAL
Full operation (n = 4)									
[17]	Whole catering service	Europe (Italy)	IC: school	LCA	Production (food and tableware) Transport Storage Cooking Waste management	Meal served at the school canteens	GWP Global Energy Requirement Acidification Eutrophication Photochemical Oxidation	✗	✗
[26]	Food service operation	USA	R	LCA	Food procurement Storage Food preparation Service	Operation of a restaurant or food service per month	Climate change Respiratory inorganics Acidification Eutrophication Fossil fuels Ecotoxicity Carcinogens Land use	✓	✗
[27]	Effect of public procurement policies	Europe (Italy)	IC: school	Carbon footprint	Food production Transport Storage Cooking and serving Waste management	Average meal	Climate impact	✗	✗
[28]	Full organisational LCA	Europe (Switzerland)	IC: canteen	LCA	Food production Processing Packaging Transport Preparation Waste management	Average main meal served in a canteen	GWP Ecological scarcity	✗	✗
Food production (n = 2)									
[53]	Food procurement	Europe (Italy)	IC: school	Carbon footprint	Farm to food service centre	1 kg of food	Climate impact	✗	✗
[54]	Food production	Europe (Italy)	IC: school	LCA	Farm to food service centre	1 kg of food	Cumulative energy demand Productive land	✓	✗
Preparation (n = 3)									
[16]	Pasta preparation	Europe (Italy)	Deferred catering	LCA	Preparation Distribution	Preparation and distribution of 1 kg of cooked pasta	Climate change Ozone depletion Human toxicity Photochemical oxidants formation Terrestrial acidification Eutrophication Ecotoxicity Metal and fossil fuel depletion	✗	✗

Table A1. Cont.

Study	Topic	Geographic Location	Type of Food Service	Type of Tool Used	System Boundaries	Functional Unit	Impact Categories	ECON	SOCIAL
Preparation (n = 3)									
[21]	Preparation: catering appliances	UK	R	LCA	Preparation Storage	Delivery of a catering service for one year	GWP	✓	✗
[45]	Environmental impact of a meal cooked at four different production scales	Europe (Spain)	R & CAT	LCA	Production Processing Packaging Transport Preparation Consumption Waste	1 kg of finished hot product ready to be consumed	Climate change Respiratory organics and inorganics Radiation Ozone layer Land use Acidification Ecotoxicity	✗	✗
Ingredients (n = 3) and meals (n = 12)									
[30]	Ingredients	Europe (Romania)	IC: university	LCA	Production Processing Transport		Energy use Land occupation	✗	✗
[31]	Ingredients	Europe (Italy)	IC: school	LCA	Food production Transportation Processing Transportation Preparation (cooking) Packaging Transportation Consumption Waste management	1 kg of food product	GWP Cumulative Energy Demand	✗	✗
[32]	Ingredients	UK	IC: school	LCA		1 kg of food product	GWP	✗	✓
[34]	Meals	UK	IC: school	Carbon and water footprint	Production Transport Preparation	One portion of a meal	GWP Water consumption	✗	✓
[35]	Meals	Europe (Italy)	IC: school	LCA LCC	Procurement Preparation Distribution Serving	Average meal	GWP Photochemical ozone creation Acidification Eutrophication	✓	✗
[36]	Meals	Europe (Finland)	R	Carbon footprint	Production Processing Cooking losses	Average meal	GWP	✗	✓

Table A1. Cont.

Study	Topic	Geographic Location	Type of Food Service	Type of Tool Used	System Boundaries	Functional Unit	Impact Categories	ECON	SOCIAL
Ingredients (n = 3) and meals (n = 12)									
[37]	Meals	Europe (Finland)	IC: school	LCA	Production Processing Distribution Preparation Plate waste	Average school lunch	GWP Eutrophication	✗	✓
[38]	Meals	Europe (Italy)	IC: university	LCA	Production	Average meal	GWP Cumulative energy demand Ozone layer depletion Photochemical oxidation Acidification Eutrophication	✗	✗
[39]	Meals	Europe (Belgium)	IC: university	Carbon footprint and Ecological footprint	Production Transport Processing	Served meal	GWP	✗	✓
[40]	Meals	Europe (Belgium)	CAT	LCA	Production Processing Packaging Transport Preparation Consumption Waste management	One meal	Resource consumption (fossil fuels, metal ores, nuclear energy, land resources, abiotic renewable resources, minerals, atmospheric resources and water resources)	✗	✓
[41]	Meals	Europe (Switzerland)	IC: university	LCA	Production Processing Packaging Transport Preparation	1 meal	GWP	✗	✗
[42]	Meals	Europe (Netherlands)	IC: workplace	LCA	Production Processing Packaging Transport Preparation Waste Management	1 kg prepared product (ready meal) at plate	GWP Land use change	✓	✓
[43]	Meals	Europe (Spain)	IC: school	Carbon footprint	Production Packaging Processing Transportation Preparation Storage	1 kg of product (ready meal) prepared and ready to eat	GWP	✓	✓

Table A1. Cont.

Study	Topic	Geographic Location	Type of Food Service	Type of Tool Used	System Boundaries	Functional Unit	Impact Categories	ECON	SOCIAL
Ingredients (n = 3) and meals (n = 12)									
[44]	Meals	Europe (Denmark)	IC: social care	LCA	Production Processing Preparation Delivery	Mass (100 g in main dish) Energy (MJ in main dish) Protein content (kg of protein in main dish)	GWP Monetised overall environmental impact	✓	✓
[48]	Meals	Europe (Italy)	IC: school	Carbon and water footprint	Food production	100g of each ingredient	GWP Water consumption	✗	✓
Waste Management (n = 18)									
[64]	Food waste	Europe (multiple countries)	IC: health, education; R & CAT	LCA	entire food service supply chain	1 kg of food item wasted	Climate and Biodiversity impact	✗	✗
[65]	Food waste	USA	R	LCA	Production, transport, consumption, waste management	1 tonne of food	Climate change Ozone depletion Human toxicity Particulate matter Ionizing radiation Photochemical ozone formation Acidification Eutrophication Ecotoxicity Land use Resource depletion	✓	✗
[66]	Food waste	USA	IC: university (all-you-care-to-eat)	LCA	Production Processing to farm gate	1 kg of food item	Climate impact	✗	✗
[67]	Food waste	USA	IC: university (all-you-care-to-eat)	Life cycle cost and Social Carbon Cost		1 kg of food item wasted	Climate impact	✓	✓
[70]	Food waste disposal strategies: AD	USA	IC: university	Economic Input-Output LCA	Manufacturing Operation	Annual management of food waste	Climate change	✓	✗

Table A1. Cont.

Study	Topic	Geographic Location	Type of Food Service	Type of Tool Used	System Boundaries	Functional Unit	Impact Categories	ECON	SOCIAL
Waste Management (n = 18)									
[71]	Food waste disposal strategies	USA	R	LCA	Waste collection Treatment Final disposal	1 Mg (1000 kg) waste, with a composition that includes 58% food waste	GWP Cumulative fossil energy demand Eutrophication Acidification Photochemical smog formation	✗	✗
[72]	Food waste	UK	Food service (not specified)	LCA	Food production Processing Distribution Meal preparation Waste management.	One tonne of avoidable food waste generated by the sector	GWP Terrestrial Acidification Photochemical ozone formation Particulate Matter Aquatic Eutrophication Human toxicity Ecotoxicity Resource depletion	✗	✗
[73]	Organic waste treatment: Food waste	China	R	LCA	Collection Transportation Pre-processing Waste treatment	Treatment of one ton of restaurant food waste	GWP Acidification Eutrophication Ecotoxicity Photochemical ozone creation potential Human toxicity	✗	✗
[74]	Organic waste disposal strategies: composting	USA	IC: university	Carbon footprint		Amount of organic waste processed in a year	GWP	✗	✗
[75]	Organic waste disposal: Food waste	Hong Kong	IC: university	LCA	Transport Treatment Waste management	1 kg of food waste to be treated	Cumulative energy demand Expected energy return on investment	✓	✗
[76]	Organic waste disposal: Waste cooking oil	Europe (Spain)	R	LCC	Waste collection Sorting Treatment	Management of WCO and solid organic waste from restaurants in the Spanish context		✓	✗

Table A1. Cont.

Study	Topic	Geographic Location	Type of Food Service	Type of Tool Used	System Boundaries	Functional Unit	Impact Categories	ECON	SOCIAL
Waste Management (n = 18)									
[77]	Organic waste disposal: Waste cooking oil	Europe (Spain)	R	LCA	Waste collection Sorting Treatment	Management of WCO and solid organic waste from restaurants in the Spanish context	GWP Abiotic depletion Acidification Eutrophication Human toxicity Photochemical ozone creation	✗	✗
[79]	Organic waste disposal: Waste cooking oil	Europe (Portugal)	R	LCA	WCO collection pre-treatment and biodiesel production	1 MJ of biodiesel	Climate Change Terrestrial Acidification Ozone Depletion Photochemical Oxidant Formation Fossil Depletion	✗	✗
[80]	Organic waste disposal: Waste cooking oil	Europe (Spain)	R	LCA and Exergetic LCA	WCO Collection Pre-treatment Delivery Transesterification	Production of 1 ton of biodiesel	GWP Abiotic depletion Ozone layer depletion Human toxicity Ecotoxicity Photochemical Oxidation Acidification Eutrophication	✗	✗
[81]	Organic waste disposal: Waste cooking oil	Brazil	R	LCA	Waste collection Biodiesel production	2028 kg of biodiesel (cradle to gate).	GWP	✓	✓
[84]	Food packaging	Europe (Italy)	Catering (not specified)	Carbon footprint	Raw material extraction Manufacturing Use and reuse Reconditioning Maintenance Recycling and waste management	Transportation of 1200 t of fruits and vegetables	GWP	✓	✗
[85]	Tableware	Europe (Italy)	R (fast food outlets)	LCA	Cutlery production Meal consumption Waste treatment	Catering of 1000 meals with the use of dis posable cutlery	GWP Eutrophication Acidification Energy resource consumption	✗	✗

Table A1. Cont.

Study	Topic	Geographic Location	Type of Food Service	Type of Tool Used	System Boundaries	Functional Unit	Impact Categories	ECON	SOCIAL
Waste Management (n = 18)									
[86]	Tableware	-	R (quick service) & CAT	LCA	Tableware production Waste collection Waste treatment	Supply of 1000 meals using 1000 single use tableware	Climate change Ozone depletion Human toxicity Acidification Eutrophication Ecotoxicity Land use Resource depletion	×	×

ECON and SOCIAL stand for economic and social considerations. The ticks indicate if the studies included any of these considerations in addition to the environmental considerations, while the crosses indicate that no such considerations were taken into account. IC: Institutional catering. R: Restaurants. CAT: contract catering/catering business.

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