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Review

Life cycle environmental impacts of food away from home and mitigation strategies—a review

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ABSTRACT

Food production and consumption are major drivers of global environmental change, endangering the safe operating space of many environmental areas. Globally, there has been a growing trend of dining out, termed food away from home (FAFH) here, but its environmental sustainability has received insufficient attention. In this review, we examine studies quantifying the life-cycle environmental impacts of FAFH and identify mitigation strategies across the food supply chain. Overall, previous life cycle assessment (LCA) studies focused on the composition of FAFH meals and pre-use life cycle stages, especially food production. Greenhouse gas (GHG) emissions of FAFH meals range from 0.134 kg CO_2 e/meal to 13.2 kg CO_2 e/meal for school canteen meals, and from 0.60 kg CO_2 e/meal to 9.6 kg CO_2 e/meal for other catering services. Meat ingredients are the dominant source in a variety of environmental impact categories, and the food production stage usually accounts for over half of the total GHG emissions in the FAFH life cycle. Supply side mitigation strategies include advancing farming practices, updating cold transportation technology, and improving building energy efficiency. Demand side mitigation focuses on dietary change towards meals with less meat ingredients, with nudging and sustainable menu-designing as the two primary groups of strategies. Areas of focus for LCA include improving modeling of building energy consumption related to food consumption, advancing uncertainty characterization of life cycle results, and capturing geographical variations in food production.

1. Introduction

Maslow's Hierarchy of Needs states that the needs of people can be divided into five different classes, from the most basic physiological needs to higher psychological needs such as self-actualization (Maslow, 1943). Food, from various sources of plants and animals, can fulfill people in ways beyond quelling hunger, influencing all categories within the hierarchy of human needs, thereby becoming an integral part of humanity. Food can be divided into two categories: food at home (FAH) and food away from home (FAFH). As an alternative to FAH, FAFH is generally defined as food and snacks prepared by either a commercial (e.g., quick service restaurants, full service restaurants, on/off premise catering, and hotel and club food service) or an institutional (e.g., school, hospital or military) food service.

Studies have indicated that worldwide eating patterns have shifted in favor of FAFH over the last few decades. FAFH is already an established part of the lifestyle in developed countries (Mottaleb et al., 2017). The fraction of households that take lunch away from home at least three times a week was found as 23.1% in Demark, 21.3% in Italy, 20.9% in Belgium and 17.7% in Poland (D'Addezio et al., 2014). FAFH accounts for 40% of the nutritional market in Germany (Pfeiffer et al., 2017), and 34% and 25% of the energy intake for U.S. and Korean working-age adults, respectively (Choi et al., 2017; Todd, 2017). Additionally, FAFH demand has been increasing in many developed countries. FAFH consumption doubled from 1997 to 2017 in the U.S., and expenditures of FAFH caught up to those of FAH in 2017 (Okrent et al., 2018). In

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Korea, the food service industry grew seven-fold from 1986 to 2012 (Choi et al., 2017).

Meanwhile, FAFH experienced a significant growth in prevalence and significance in emerging countries. The share of FAFH increased 25% from 2002 to 2009 in Brazil (Claro et al., 2014). In 1995, urban Chinese consumers spent <10% of food expenditures on FAFH, but the value increased to 15% in 2000 and to 22% in 2009 (Zhou et al., 2012). This rising trend of dining out is due to many factors, including increasing income, food availability, and female employment (Liu et al., 2015; Okrent et al., 2018; Okrent and Alston, 2012), as well as improved accessibility to restaurants and busier lifestyles (Pfeiffer et al., 2017; Pinho et al., 2018). Furthermore, actual FAFH consumption worldwide may be greater than available data due to the inherent error associated with data acquisition processes, such as questionnaire design, extrapolation algorithms and consumers' feedback (Fiedler and Yadav, 2017; Smith et al., 2014).

Studies have thoroughly examined the various attributes of FAFH such as nutrition, economy, safety, society, and religion, offering great insights into how consumers choose their food. Efforts by governments worldwide have also been made to improve food safety, nutritional quality, and food availability. The sustainability of FAFH, however, is still in its early stage of research and has not yet gained much attention from governments.

On the other hand, the food system is a main driver of global environmental degradation (Jaramillo and Destouni, 2015). For example, it accounts for ~26% of anthropogenic greenhouse gas (GHG) emissions with both intensive and extensive agricultural practices, ~32% of global terrestrial acidification, and ~78% of eutrophication (Poore and Nemecek, 2018). If current diet trends continue, the food system will be responsible for ~80% of future increases in GHG emissions due in part to large-scale agricultural production and land clearance (Tilman and Clark, 2014). With cropland and pasture occupying the largest land surface (Foley et al., 2005), the food system has also been a major threat to biodiversity (Tilman et al., 1994). These significant impacts explain why the food system is at the heart of the agenda for future development by the United Nations (U.N.) (Chaudhary et al., 2018). At least 12 of the 17 *U.N. Sustainable Development Goals 2015 – 2030* are related to food and agriculture (Griggs et al., 2013; United Nations, 2015). Most notably, Goal 2 (end hunger, achieve food security and improved nutrition, and promote sustainable agriculture) and Goal 12 (ensure sustainable consumption and production patterns) concentrate on food's environmental burden. However, the environmental sustainability of food is the least important consideration in meal choice (Sala et al., 2017).

The studies above indicate that the food system contributes significantly to global environmental change, and FAFH plays an important and growing part. These studies also suggest that the previous "Green Restaurant" approaches (e.g., Baldwin et al., (2011); Hu et al., (2010)), which focus solely on energy efficiency improvement and FAFH facility management, may be insufficient to achieve the goal of environmental sustainability of FAFH due to neglecting the embodied environmental impact of the food items. We need to first understand the environmental impacts of the FAFH system and then to identify the mitigation opportunities from a life cycle viewpoint, including the foods' production, processing, distribution, use, and waste disposal. Life cycle assessment (LCA) is a systems approach widely applied to evaluate products' environmental impacts (ISO, 2006). It quantifies environmental emissions and resource use along the entire life cycle of a product or a service from resource extraction to disposal, to identify greener alternatives and avoid burden shifting between life cycle phases or between environmental impact areas (Lee et al., 2012; ISO, 2006; Yang et al., 2012). LCA has greatly improved our knowledge of sustainable food choices (Heller et al., 2018b; Heller and Keoleian, 2003; Roy et al., 2009).

In this study, we review existing life cycle assessment (LCA) studies on FAFH to better understand the magnitude of FAFH environmental impacts and to determine the key contributors within the system. We then identify and summarize mitigation opportunities or strategies along the life cycle of the food system. Section 2 describes how we found the 15 studies were selected Section 3 reports on how we analyzed these 15 studies following the four steps of a LCA framework (i.e. goal and scope, life cycle inventory, life cycle impact assessment, and interpretation) as applied to FAFH. For each step, we identified the common characteristics and categorized the studies into groups when possible to reveal state-of-the-art research strategies. Section 4 summarizes the mitigation strategies from both supply and demand sides. In the last section, we identify research gaps and challenges revealed by the selected studies.

2. Literature search

We followed the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA) protocol (Liberati et al., 2009) for a literature search. On August 6, 2019, we searched the Scopus with keywords ("LCA" OR "life cycle assessment" OR "carbon" OR "footprint" OR "label" OR "eco-label") AND ("food away from home" OR "away from home" OR "restaurant" OR "canteen" OR "fast food" OR "food service" OR "Café" OR "Cafeteria"). We also screened the titles and abstracts of the "related studies" provided by the Scopus system. We focused on articles written in English and published in peer-review journals. The remaining studies were filtered based on the following criteria:

1. *Extensivity and generality.* Studies on a single item served in FAFH scenarios were excluded, and only LCA studies at a meal level were included.
2. *Consistency.* Only foods that are prepared out-of-home and ready-to-eat are regarded as FAFH. Studies on ready-to-eat meals requiring reheating were excluded.
3. *Depth and representativeness of LCA.* Studies focusing on the design and effectiveness of eco-labels were excluded.
4. *Inclusion of embodied environmental impacts.* Studies focusing only on the on-site environmental impact of food without considering upstream processes like food production were excluded. Such studies usually consider only the background activities of building operation (e.g., electricity use).

More details of the literature search are included in the Supplementary Information. By this process, we identified a total of fifteen LCA studies on FAFH.

3. The life-cycle environmental impacts of food away from home

3.1. Types of meals studied

The fifteen studies covered three types of meals: typical meals, recommended meals, and average meals (Table 1). Three studies are on district-averaged meals, and food groups, instead of specific ingredients, are used for their LCA. Eight studies were conducted based on a school canteen scenario, and food ingredients were specified for LCA in these studies.

Overall, the selected studies on FAFH LCA had a similar workflow as meal-level LCA studies on food at home (FAH) (e.g. van de Kamp et al., (2018) for typical meals, Behrens et al., (2017) for nutritional recommendation meals, and Berners-Lee et al., (2012) for national averaged meals). They conducted LCA by two steps: meal determination and a usual LCA procedure (Fig. 1). The meal determination step identifies the ingredient types/food groups and quantifies the corresponding amounts within the meal under concern. This step is separated from the functional unit determination in meal-level LCA studies because 1) it can take a large amount of effort, and 2) the ingredients act as the real functional unit in LCA. In this step, for typical meals and recommended meals, ingredients are usually directly determined from menus and recipes (or the recommended recipes from an organization or meal

Table 1
Results of the literature search.

ID	Reference	Meal Description[a]
1	Saarinen et al., (2012)	A nutritional sound lunch model for school canteen (R) A modification lunch from actual school lunches (T)
2	Jungbluth et al., (2016)	Annual averaged meal in 240 company canteens (A)
3	Pulkkinen et al., (2016)	105 common lunches in commercial restaurant (T)
4	Benvenuti et al., (2016)	106 different dishes of the Mediterranean cuisine for school canteen (T)
5	Chen et al., (2016)	Meals with 19 most used ingredients in a school canteen (A)
6	Ribal et al., (2016)	1 kg of product, prepared and ready to eat for school canteen (T)
7	Schaubroeck et al., (2018)	200 g of served meal component portion in a university canteen (T)
8	Calderón et al., (2018)	A typical meal served by a catering company for school (T) A typical meal served by a commercial restaurant for school (T)
9	Cerutti et al., (2018)	An average school meal (A)
10	Mistretta et al., (2019)	A meal equivalent to the annual food consumption for school canteen (A)
11	Saxe et al., (2019)	Five categories of dependent senior meals (T)
12	de Laurentiis et al., 2018	24 recipes of recommended meals in a school canteen (R)
13	Li et al., (2019b)	Per capita food consumption in hotel/restaurant/café in China (A)
14	Song et al., (2019)	Averaged daily consumption in China (A)
15	Li et al., (2019a)	Averaged daily FAFH consumption in China (A)

[a] T: Typical meal; R: Recommended meal; A: Averaged meal.

composition) (Table 1). On the other hand, data collection for averaged meals is more complex, which is completed by either averaging the food ingredient consumption during a period of time (e.g., the annual food consumption in company canteens (Jungbluth et al., 2016) or in school canteens (Mistretta et al., 2019), or by conducting surveys (e.g., Song et al. (2019) and Li et al. (2019a)). Additionally, the results of LCAs require further processing (e.g., characterization) in cases where the goal extends beyond environmental impact quantification towards communication with customers or policymakers.

3.2. The goal and scope of the LCA studies

The goal and scope step in LCA defines the question to be examined, the intended application and the targeted audience (Guinée, 2002). The goal of the selected studies can be divided into three categories: quantification, policymaking, and "Nudging" (Fig. 2), or influencing consumer decisions by modifying their choice architecture (e.g., providing more information and changing default choices but without a monetary incentive (Münscher et al., 2016; Schubert, 2017)). The value of nudging has been increasingly recognized by policymakers (BIT, 2016; Halpern, 2016).

Each of the selected studies included at least one case study of quantification, while the policy studies and the nudging studies are separated by target audience. The policy studies targeted facility management department or policymakers for green policymaking (e.g., menu design and supplier selection), and nudging studies targeted customers for providing information. Notably, four studies aimed to develop a framework for food choices considering a variety of factors (e.g., environmental sustainability, nutrition, and economics) (Benvenuti et al., 2016; Chen et al., 2016; Ribal et al., 2016; Schaubroeck et al., 2018).

The scope of the selected studies is diverse, from focusing on only cradle-to-farm LCA to covering the whole life cycle (Table 2). All selected case studies covered food production in the system boundary, however, given its significance.

3.3. Life cycle inventory (LCI) analysis

Life cycle inventory (LCI) analysis quantifies the energy use, material use, environmental emissions, and waste in each life cycle stage. This step is generally recognized as the most resource-intensive and time-consuming step in LCA (Yang, 2016). The level of effort for LCI analysis among the selected studies is diverse (Table 2), depending in part on the purpose of a study. For example, Song et al., (2019) sought to determine the trend of FAFH consumption in China and the corresponding change of environmental impact. Thus, its focus was more on determining an average meal than on LCA.

The main stage that FAFH differs from FAH is the use stage, i.e. how food is prepared and cooked. Unlike FAH, FAFH facilities are usually characterized by a highly centralized kitchen, a high energy intensity from the heating, ventilation and air conditioning (HVAC) system, and high standards for cold storage and sanitation. The environmental impacts of the FAFH use stage, mainly via energy use, are estimated by two different approaches. The first is to use the yearly averaged energy consumption by the meal supply activities (Cerutti et al., 2018; Jungbluth et al., 2016), and then dividing the total energy consumption by the number of meals. This approach includes all the energy end-users in

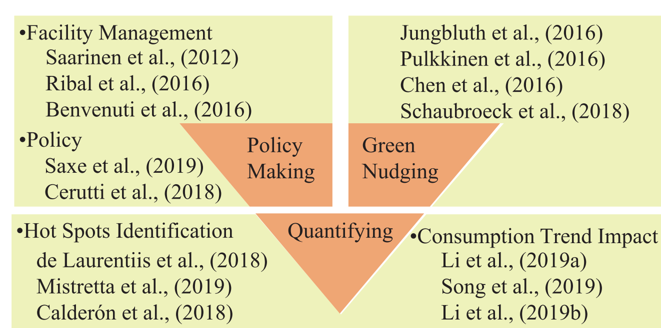

Fig. 2. A summary of the goal of the selected FAFH LCA studies.

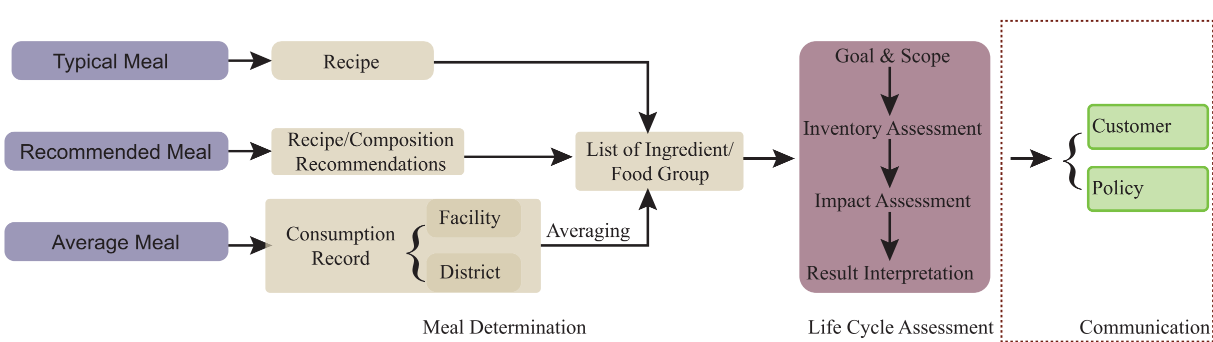

Fig. 1. Workflow of life cycle assessment on food away from home meals.

Table 2
Effort level of life cycle inventory of selected case studies*.

ID	Reference	Effort Level**				
		Production	Processing	Distribution	Use	Disposal
1	Saarinen et al., (2012)	High	Medium-Low	Medium-Low	N/A	N/A
2	Jungbluth et al., (2016)	Medium-Low	Medium-Low	Medium-Low	High	High
3	Pulkkinen et al., (2016)	Low	Low	Low	Low	N/A
4	Benvenuti et al., (2016)	Low	N/A	N/A	N/A	N/A
5	Chen et al., (2016)	Low	N/A	N/A	N/A	N/A
6	Ribal et al., (2016)	Medium-Low	Medium-Low	Medium-Low	Medium-Low	N/A
7	Schaubroeck et al., (2018)	Medium-High	Medium-High	Medium-Low	N/A	N/A
8	Calderón et al., (2018)	High	High	High	High	Medium-Low
9	Cerutti et al., (2018)	Medium-Low	Medium-Low	High	High	High
10	Mistretta et al., (2019)	Medium-Low	Medium-High	Medium-High	Medium-High	Medium-High
11	Saxe et al., (2019)	Medium-High	Medium-High	High	High	N/A
12	de Laurentiis et al. (2018)	Medium-Low	Medium-Low	Medium-Low	Medium-High	N/A
13	Li et al., (2019b)	Low	N/A	N/A	N/A	N/A
14	Song et al., (2019)	Low	N/A	N/A	N/A	N/A
15	Li et al., (2019a)	Low	N/A	N/A	N/A	N/A

*We ranked the effort level of each of the life cycle stages from low to high. The overall effort level of the selected studies ranges from those covering only cradle-to-farm gate and employing simplified LCA with database data to those covering cradle-to-grave and collecting primary data for most of the foreground processes.
**N/A: life cycle stage not covered; Low: data from secondary data without modification; Medium-low: data from secondary data sources with modifications in forms of discussion of inclusion and exclusion of subprocesses; Medium-High: data from modeling or data from secondary data sources but modified with clear clarification; High: primary data collection for the main foreground activities of the stage. The results of the evaluation are based on the description of the texts of the reviewed paper. The effort level does not necessarily reflect the quality of the study but is highly dependent on the goal of the study and data availability. Within the life cycle of FAFH, the data availability in the production stage is large, and data is relatively easy to obtain due to the large number of LCA case studies on the production of single food items. The quantification of material and energy inputs for processing and transportation requires more effort, but the intensity of emission from these processes (i.e. the emission factor) can be accessed via databases such as eco-invent (Wernet et al., 2016).

a restaurant but cannot obtain food-specific data directly. The second approach is to use data or models representing household meal serving scenarios (de Laurentiis et al., 2018; Sonesson et al., 2003). This approach obtains food-specific estimates but generally underestimates the energy demand since it includes only the energy usage by cooking and refrigeration, which collectively contribute less than 50% of the total restaurant energy consumption (Thornton et al., 2011). Results of the selected studies showed that GHG emissions from use stage are ~40% of those from production stage estimated using the first approach and ~10% using the second approach.

Waste is the other stage where FAFH differs significantly from FAH. In FAH, food waste is usually mixed with other types of waste and then sent to a landfill. Food waste in FAFH is more distinguishable due to its large fraction within the waste streams. Food waste is the dominant (30–60%) source of restaurant waste (Austin Resource Recovery (2012); CDM (2010); Hogan et al., 2006; RIRRC (2015); Tatàno et al., (2017); Wilkie et al., (2015); and WRAP (2011)). Food waste can be generated throughout the whole process of food storage, preparation, and cooking in FAFH facilities. In the U.K., for example, these areas contribute 21%, 45% and 34%, respectively (WRAP, 2013). Food waste is also a major source of municipal solid waste (MSW) sent to landfills (De Clercq et al., 2017), generating large amounts of GHG emissions. Thus, including the waste disposal stage is essential for determining the total overall impacts of FAFH. Food waste from the use stage was the primary focus of many of the selected studies, quantified by either on-site monitoring (Cerutti et al., 2018; Jungbluth et al., 2016) or by assumption (e.g., ~20% of cooked food turning into waste (Calderón et al., 2018).

3.4. *Life cycle impact assessment and result interpretation*

Most of the selected studies chose mid-point impact categories in the life cycle impact assessment (LCIA) step (Table 3). GHG emissions, water footprint, and ecological footprint were the most examined categories, which are closely related to agricultural production. Additionally, all the "nudging" oriented studies used GHG emissions as a metric to communicate the information to customers because it is more widely recognized than other indicators.

Different strategies were applied to convey results to customers when

Table 3
A summary of life cycle impact assessment by the selected studies.

ID	Reference	Impact Category	Life Cycle Impact Method/ Data Sources
1	Saarinen et al., (2012)	GHG emissions, eutrophication	Ipcc method; emission factors from eco-invent
2	Jungbluth et al., (2016)	Eco-points; GHG emissions	Ecological Scarcity Method 2006
3	Pulkkinen et al., (2016)	GHG emissions	Emission factors from LCA literature/database
4	Benvenuti et al., (2016)	Water footprint, GHG emissions	Emission factors from LCA literature/database
5	Chen et al., (2016)	Water Use, land use, GHG emissions	Emission factors from LCA literature
6	Ribal et al., (2016)	GHG emissions	Emission factors from LCA literature
7	Schaubroeck et al., (2018)	GHG emissions; eco-logical footprint, cumulative exergy extraction; water use	Natural Environment v2013 Method; Recipe,
8	Calderón et al., (2018)	All the eco-indicator 99 environmental impact categories	Eco-indicator 99
9	Cerutti et al., (2018)	GHG emissions	Emission factors from (EC-JRC, 2011)
10	Mistretta et al., (2019)	Global energy requirement; acidification; eutrophication; GHG emissions; photochemical oxidation	Global energy requirement estimation; characterization factors from environmental product declaration
11	Saxe et al., (2019)	GHG emissions; monetized impact	Consequential data from eco-invent 3.3
12	de Laurentiis et al., 2018	GHG emissions	Emission factors from literature
13	Li et al., (2019b)	Ecological footprint	Coefficients of ecological footprint from literature
14	Song et al., (2019)	Water footprint	Water footprint data from Barilla Centre for Food & Nutrition
15	Li et al., (2019a)	GHG emissions	Emission factors from Barilla Centre for Food & Nutrition

multiple impact categories were examined. For instances, Schaubroeck et al. (2018) argued that a scoring system should be simple to understand and apply, and it also should be able to distinguish different food items. Thus, their study employed a single scoring system based on the LCA results of ecological footprint. On the other hand, Chen et al. (2016) used three distinct metrics and identified their scoring system's advantages as an easier path to success, a reflection of key concerns, and a revelation of trade-offs among different environmental impact categories.

GHG emissions of FAFH meals from the selected studies show a wide variation, ranging from 0.134 kg CO_2 e/meal (de Laurentiis et al., 2018) to 13.2 kg CO_2 e/meal (Benvenuti et al., 2016) for school canteen meals, and from 0.60 kg CO_2 e/meal (Pulkkinen et al., 2016) to 9.6 kg CO_2 e/meal (Saxe et al., 2019) for other catering services. These results are difficult to compare due to differences in scope, life cycle inventory data, and the choice of LCIA models. A consistent finding is that meat ingredients are the most important source of GHG emissions, and food production is the dominant life cycle stage of FAFH and usually accounts for >50% of the total GHG emissions. Thus, a diet change toward less meat and more plant consumption was often identified by the selected studies as the most effective solution for mitigating the environmental impact of FAFH.

4. Mitigation of environmental impact of food away from home

4.1. Mitigation strategies from the supply side

4.1.1. Food production stage

The studies reviewed have recommended a variety of strategies for mitigating the life cycle environmental impact of FAFH (Table 4). In the food production stage, strategies to improve system efficiency via changing management practices and adopting more advanced technologies were commonly recommended (e.g., farming practice substitution strategy, agroecological design, and multidiscipline cooperation (Lichtfouse et al., 2009), and precision farming for the livestock sector (Berckmans and Hendrawan, 2014; Kaufmann, 2015; Tullo et al., 2019),).

4.1.2. Use stage

Energy usage is the main source of environmental impacts at the use stage. Therefore, a sustainable energy supply has been identified as a critical solution for restaurants' environmental performance (Mistretta et al., 2019). Additionally, improving on-site operational energy efficiency is also important, which could be achieved by 1) enhancing building envelopes (e.g., improving building opaque insulation, using high-performance window glazing and cool roofs (Zhang et al., 2011)); 2) using high-efficiency appliances for lighting, cooking, and HVAC (Zhang et al., 2011); and 3) applying on-site heat recovery by incorporating the dishwasher (De Paepe et al., 2003; Persson, 2007; Wemhoff et al., 2017) or HVAC system (Onyango et al., 2012; Wang et al., 2017). Governments could play an impactful role by providing financial incentives for promoting energy-efficient certified appliances (e.g., the ENERGY STAR™ products (Worrell et al., 2013) and by regulating energy efficiency standards (e.g., the requirement of lowest annual walk-in energy factor (AWEF) for walk-in coolers and refrigerators (EERE, 2017)). Finally, environmentally conscious management can reduce excess energy usage and involves improving recycling and composting, pollution prevention, and employee education (GRA, 2016; Hu et al., 2010). For example, Mudie et al. (2016) examined the electricity usage in fourteen U.K. public house-restaurants and found that 70% and 45% potential electricity savings could be gained from addressing behavioral factors and poor maintenance, respectively.

4.1.3. Food waste

The high embodied environmental impacts of food ingredients suggest that avoiding food waste can be an important mitigation opportunity. At the food distribution stage, during the transport of animals to slaughterhouses (Corrado et al., 2017), food waste can be reduced by adopting advanced cold transportation technologies such as incorporating a time-temperature management system (Mercier et al., 2017) and by developing cold chain databases (Gogou et al., 2015). At the food processing stage, trade-offs exist between material usage and food protection: increasing the use of packaging material may reduce the net environmental impact through reducing food waste, though the impact of the packaging itself would increase (Heller et al., 2018a; Molina-Besch et al., 2018; Wikström et al., 2018). Additionally, food waste generated after on-site usage, due to bad storage or over-preparation, could be reduced through better food waste management in FAFH facilities toward food waste identification, quantification, and reduction (WRAP, 2011). Site-specific determination is required to obtain the GHG emission factors for food waste per Lopez et al. (2016), which showed that average rates of methane release for food waste from a university dining hall, a hotel kitchen, and a restaurant are 363, 492 and 403 mL/dry g, respectively.

Table 4
Mitigation recommendations from selected studies.

ID	Reference	Life Cycle Stages	Mitigation Method
1	Saarinen et al., (2012)	Production	Choose seasonal/organic ingredients
		Distribution	Local harvested ingredients
		Demand Side	Diet change (vegetarian diet; replacing beef/fish with pork/chicken)
2	Jungbluth et al., (2016)	Production	Reduction of fruits and vegetables cultivated in heated greenhouses
		Distribution	Reduction in share of air-freight
		Use	Increase canteen operation energy efficiency
		Demand Side	Reduction of the average quantity of meat per meal
3	Pulkkinen et al. (2016)	Demand Side	Nudging (eco-labeling)
4	Benvenuti et al., (2016)	Demand Side	Sustainable menu optimization
5	Chen et al., (2016)	Demand Side	Nudging (smartphone applications)
6	Ribal et al., (2016)	Demand Side	Sustainable menu optimization
7	Schaubroeck et al., (2018)	Demand Side	Eco-labeling
8	Calderón et al., (2018)	Production	Technique advances in agriculture; reduction of fruits and vegetables cultivated in heated greenhouses
		Distribution	Reduction in share of air-freight
		Use	Using of high scale systems
		Demand Side	Diet change
9	Cerutti et al., (2018)	Production	Different production practices
		Use	Change electricity sources
		Waste	Optimization of the recycling/composting of waste
		Demand Side	Change food component in the diet
10	Mistretta et al., (2019)	Production	Reducing the impact of food production
		Distribution	Local provision
		Use	High-efficiency appliance/choose electricity from renewable source
		Demand Side	Reduction in meat consumption
11	Saxe et al., (2019)	Distribution	Less frequency of meal delivery
		Supply Side	Choose less impacting beef
		Demand Side	Change default choices (cut-down on beef meals; beef-free Monday; avoid high impact meals)
			Affecting menu-design (beef tax)
			Nudging (quantifying impact of all meals)
12	de Laurentiis et al., 2018	Demand Side	Diet change

4.2. Mitigation strategies from the demand side

4.2.1. Diet change

A shift toward less-meat-more-plant diets was the most commonly recommended strategy (Table 4) because of its potential effectiveness, considering the remarkably greater impacts of meat products along with other benefits (e.g., health (Clark et al., 2019)) The various goals of the selected studies, as discussed in Section 3.2, suggest that FAFH is an important platform for promoting diet change. In FAFH scenarios, customers can be exposed to the environmental impacts of their food prior to ordering, and facility management offices could choose more environmentally friendly ingredients. Accordingly, the strategies for achieving diet change suggested by the selected studies (Table 4) can be categorized into two groups: nudging and sustainable menu redesign. Nudging can be applied where customers could freely choose their own dishes (e.g., university canteens and restaurants). Sustainable menu design, on the other hand, can be applied in scenarios where customers have limited food choices. The two strategies are discussed in detail below.

4.2.2. Nudging

Although research has shown considerable differences in environmental impacts across different food categories, most consumers are unaware of this information (Hartmann and Siegrist, 2017) and tend to underestimate food-related emissions (Camilleri et al., 2019), so environmental sustainability is not among the criteria of their meal choices. However, consumers' decision architecture could be modified when information is provided (Münscher et al., 2016; Schubert, 2017). Eco-labels are a key instrument that provide consumers with product information (Goossens et al., 2017; Lo et al., 2017) and to convey environmentally friendly options (Liu et al., 2016). Consumers' decisions tend to be affected by the presence of labels due to their general desire to maintain an attractive self-image (Schubert, 2017). Studies have shown that even though the public's awareness of the connection between food and the environment is low, most people are interested in climate-friendly food consumption (e.g., Pulkkinen et al. (2016); Brunner et al. (2018)). Eco-labels are also a potential complement to nutritional labels and can be applied in various designs and forms (e.g., color-coding and footprint (Camilleri et al., 2019; Filimonau et al., 2017; Filimonau and Krivcova, 2017)).

Rearranging default choices is another form of nudging. Default choices are often considered to be informative and prepared by someone or an institute with credibility, so they tend to be trusted by the consumer (Sunstein, 2017). Additionally, consumers tend to take default choices due to inertia when they have no previous preferences, and active decision making requires additional effort (Schubert, 2017). Whereas the food market is not a place "where consumers are generally protected from harm (Cohen (2018))," providing customers with well-chosen cheaper, healthier, and environmentally friendly alternatives as default choices for promoting diet change can bring about significant economic, health, and environmental benefits (Sunstein, 2017; Sunstein and Reisch, 2014).

Social media could also become a nudge by stimulating peer comparison and providing a platform for promoting green behavior. Eating out is a social activity, which is even true in the current "eat with your eyes" era where social media is highly developed. Instagram, the most used photo-sharing application, had a total of over 350 million posts marked #food by August 2019. Social media has been already applied as a health-promotion tool for providing the consumer with information, material aid, and encouragement from friends and family (Jane et al., 2018), which can be potentially expanded to promote green behavior.

4.2.3. Sustainable menu design

The reviewed studies have presented a systematic sustainable menu design approach characterized by three aspects (Table 4). First, sustainable menu design requires mitigating the environmental impact from the food provided to customers. Three additional hurdles to develop healthy and sustainable meals exist beyond the challenge of quantifying environmental impact: the composition of meals (i.e., first course, second course, and side dish), the weekly and monthly repetition of dishes, and the repetition of food categories (Benvenuti et al., 2016). Second, sustainable menu design requires selecting a proper food supplier (Saxe et al., 2019; Schaubroeck et al., 2018). Finally, governmental policies should be enacted to promote and standardize widespread menu design aiming at maintaining a balance among economy, nutrition, and environmental sustainability via monetary incentives and nutritional guidance. Here, we discuss two typical factors: greenhouse gas taxes and the modification of nutritional guidelines.

The effectiveness of levying taxes on high-impacts foods like meat to reduce their demand is uncertain and the policy may lead to other social and economic consequences. Models generally show that such a policy can be effective (e.g., Springmann et al. (2017); Bonnet et al. (2018)). However, a critical review of several policies aimed at reducing obesity and promoting healthy diets has found that none of them had a meaningful impact in experiments, suggesting that a combination of different policies may be needed (Cawley and Wen, 2018). Another broader review of a wide range of policy interventions found mixed or inconclusive results, pointing out complications in evaluating the effectiveness of policy interventions (Capacci et al., 2012). Furthermore, since the food service industry is highly competitive, raising costs as a result of taxation may lead to unintended consequences such as endangering business success (Filimonau and Krivcova, 2017). FAFH is also considered an important factor of social welfare (Farfan et al., 2015): green taxing may disproportionally affect the poor, worsening social inequality since taxation may result in meat consumption becoming a privilege only for the wealthy.

Nutritional guidelines are science-based food consumption recommendations that help a country's citizens make healthy decisions regarding their food consumption (Flock and Kris-Etherton, 2011). Nutritionally-recommended meals are also one of the three types of FAFH meals among the selected studies. Future dietary guideline development needs to advance the consideration of environmental sustainability aspects (Blackstone et al., 2018). A nutritional guideline is incomplete if the indirect health impact from the environmental degradation associated with the food system is ignored (Tuomisto, 2018). The national nutritionally-recommended meals generally have lower GHG emissions than current diets, but a large variation of GHG emissions exists among the global nutritional guidelines, from 687 kg CO_2e capita^{-1} yr^{-1} in India to 1579 CO_2e capita^{-1} yr^{-1} in the USA (Pernollet et al., 2017; Stehfest, 2014; Van Dooren et al., 2014). However, even if the nationally recommended diets were widely adopted, it would still fall short of the Paris Agreement goal to limit global warming to well below 2 °C (Ritchie et al., 2018; UNFC on Climate Change, 2015).

5. Research gaps and recommendations

5.1. Improving energy usage modeling in restaurants

Existing studies examine the life cycle environmental impact of FAFH meals in a variety of scenarios (e.g., primary school canteens, company canteens, commercial restaurants, and self-select university canteens). These studies mainly address the compositions of FAFH meals and use a diversity of LCA methods in terms of scope, system boundary coverage, and life cycle inventory methods and data. The methodology needs improvement to better communicate environmental information to the public for nudging. Here, we discuss three research gaps among the existing studies: one about FAFH facility energy modeling and two about food LCA modeling (i.e. regionalization and uncertainty). Addressing these gaps may require international cooperation and advancing the standardization of the LCA framework.

First, the use stage of FAFH was not fully characterized by the selected studies (Section 3.3) due to two challenges. First, energy consumption in restaurants is highly aggregated, but needs to be disaggregated and allocated to each food item/ingredient defined in the functional unit (Fig. 3). Energy usage patterns in restaurants also increase the complexity of the allocation since multiple tasks are often performed simultaneously for end-use groups. The second challenge is that energy consumption in restaurants is highly variable. Although the heat gain from a specific cooking process depends on the appliance type and the energy input rate (Swierczyna et al., 2009), the extra energy requirement for removing this part of heat gain (i.e. the cooling load) is subject to external conditions and varies by time and location.

The databases or models used in the selected studies did not address these challenges, as discussed in Section 3.3. Methods that are rapidly growing in areas such as building energy efficiency improvement can be potentially used for modeling the use stage of FAFH. These methods include experiments, non-intrusive load monitoring (NILM), whole-building energy modeling, and advanced statistical methods. Experimental studies are performed by installing sub-metering systems for water, gas, and electricity usage (Ahmad et al., 2016). Experimental measurements are the most accurate approach but are too costly for large-scale studies, especially considering geographic variations. NILM, which disaggregates load data from smart meters to each appliance, is a promising technology for determining energy consumption in FAFH facilities, benefiting from a growing application of smart electricity meters and improvements in machine learning algorithms (Kelly, 2016; Kim et al., 2017). Whole-building energy modeling is a reasonably accurate and flexible approach for examining different energy consumption patterns in different climate regions and is widely applied in the simulation of energy consumption in new buildings or retrofit designs. The models are based on the construction structure, internal loads (e.g., people, gas and electrical appliances) and their schedules, and HVAC systems. Finally, machine learning algorithms have been applied to improve building modeling (e.g., Robinson et al. (2017); Rahman and Smith (2017)). These more complex statistical models are promising in their ability to capturing geographical and temporal variations within restaurant energy consumption. To maximize their accuracy, however, significant data collection is required.

5.2. Addressing the geographical variations of agricultural systems

LCAs, which originated in manufacturing sector applications, have conventionally relied on spatially generic data (Miller et al., 2006), as was done in all the identified studies. However, agricultural systems vary greatly across regions, and considering the significance of food production in FAFH meals, a regionalized approach is required to more accurately estimate their life cycle environmental impacts (Yang et al., 2020). Current LCA databases, such as Eco-invent (Moreno Ruiz et al., 2013), Agri-Footprint (Durlinger et al., 2014) and AGRIBALYSE (Koch and Salou, 2015), provide most data at global or country levels and thus do not capture geographic variations. Also, many datasets in commercial databases are outdated due in part to the cost and time needed in regular updating, and also to data gaps that may misrepresent current food systems.

Three potential approaches exist to address the challenge of geographic variability in agricultural LCA. The first approach is to incorporate spatial data that are already available (USDA (2010); Yang et al., (2012)). For example, the U.S. Department of Agriculture (USDA) publishes state-level data on the use of agrochemicals such as fertilizers, herbicides, and pesticides for top-producing states (NASS, 2017). The second approach is to downscale available spatial data to more refined resolutions based on reasonable assumptions and additional data, or to extrapolate to regions of interest based on regions with data. Pelton (2018), for example, estimated county-level N fertilizer use and emissions by corn in the U.S. based on USDA state-level survey data. The third approach is to develop parametrized spatial models that can be applied to different regions when certain key parameters are given. An example of this is the pestLCI model (Dijkman et al., 2012), which can estimate the fraction of a pesticide that ends up in the air, surface waste and groundwater when given information such as the biochemical property of the pesticide, its application time, and the soil and precipitation characteristics. Additionally, Dai et al. (2020) put forward a data processing method for building a life cycle inventory. Their method avoids the common aggregation process in the existing databases but retains the geographical and temporal variations via building a relationship between the planting characteristics and the amount of input based on multilevel modeling (MLM). LCA studies can also benefit from sophisticated biogeochemical models, such as DayCent and DNDC, which have already been developed and are widely used in agroecological modeling (Giltrap et al., 2010; Parton et al., 1998).

5.3. Uncertainty quantification

Releasing credible and transparent environmental impact information to the public needs an improvement in uncertainty quantification within the current LCA framework. As a reference criterion, the acceptable uncertainty of nutritional labels, as allowed by the U.S. Food and Drug Administration, is 20% (U.S. Food & Drug Administration, n. d.) and can be determined using standard industrial processes. Currently, uncertainty quantification in LCA is still optional according to the ISO standards, and there is a lack of clear guidance on uncertainty quantification (Ross and Cheah, 2018, 2017). Since LCA results are nearly impossible to be validated (Yang and Heijungs, 2018), uncertainty is difficult to quantify through a comparison with a known physical quantity. Not surprisingly, none of the selected studies conducted uncertainty analysis, but the existence of a variety of uncertainty

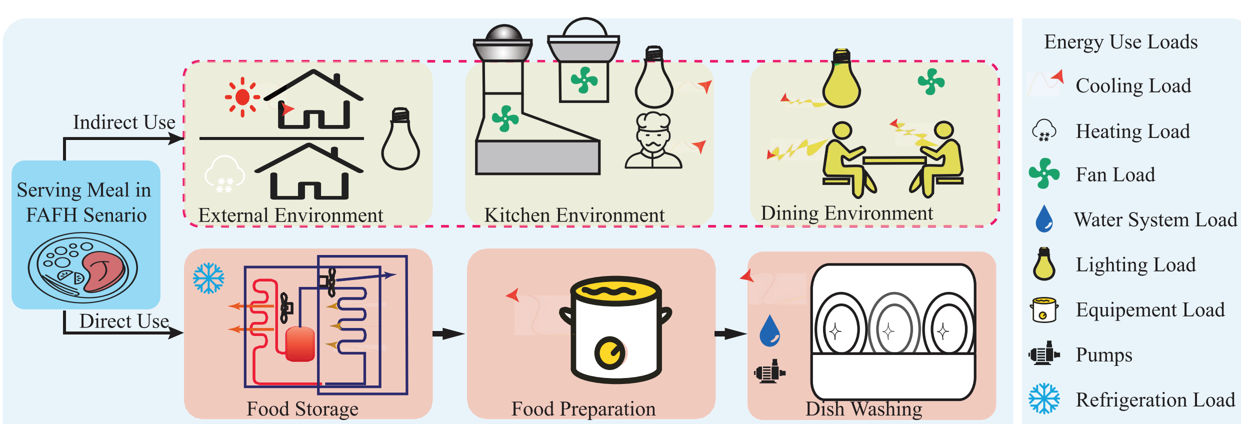

Fig. 3. The system of energy consumption in a food away from home facility.

sources was generally acknowledged. In addition, no standard exists for the acceptable uncertainty associated with environmental impact values released to consumers.

To achieve a systematic uncertainty quantification standard for FAFH, it is first recommended that technical criteria be set for conducting meal-level LCA. The selected studies showed a variety of methods in terms of, for example, the selection of system boundary and environmental impact category. Methodology guidelines for environmental green nudges are thus needed to allow practitioners to work on a consistent system boundary (e.g., life cycle stages to be covered) with consistent assumptions (e.g., surrogate data to be used). Second, the development of a fully quantitative uncertainty characterization method is required. Uncertainty characterization is the process of assigning and determining a proper mathematical structure for the uncertainty (Oberkampf and Roy, 2011). The pedigree approach, based on probability distribution, is often used in LCA to characterize uncertainty. However, it may not suit green nudges since it is semi-quantitative and dependent on the practitioner's subjective judgment of data quality (Muller et al., 2016), which may lead to false confidence and mislead the public (Kuczenski, 2019). Although other methodologies exist (e.g., variance, fuzzy sets, and multiple scenarios (Igos et al., 2018)), each approach has its own limitations and uncertainty in LCA is rarely fully quantified. Dai et al. (2020) proposed a fully quantified uncertainty characterization method using MLM to build a relationship between the geographical and temporal quantified characteristics and the material/energy inputs. Secondary data users determine the amount of material input from MLM and characterize its associated uncertainty with the prediction interval. The uncertainty is thus fully-characterized since it only depends on model performance.

6. Conclusions

In this study, we focus on the environmental sustainability of food away from home (FAFH). Improving the understanding of the life cycle environmental impacts of FAFH is essential since the trend of dining out has been rising globally. We provide a summary of current LCA studies on FAFH and identify the existing challenges within the current LCA framework.

The number of available LCA studies on FAFH is limited in the literature considering the significance of the issue. A diversity in methodologies is seen in each of the LCA steps. Diet change has been identified by the selected studies as a strategy for reducing the environmental impact of FAFH. FAFH can be a platform to connect customers and policymakers via nudging and menu redesigning. Challenges exist to quantifying the total and diet-level life cycle environmental impacts associated with FAFH, but potential solutions have been identified to overcome these challenges. Restaurant energy use particularly needs to be better estimated and the geographical variation of agricultural systems needs to be better captured in order to improve the overall accuracy of FAFH LCA results. LCA guidelines that define a consistent scope of the FAFH system, choice of assumptions, and uncertainty characterization are needed to ensure comparable results across studies and to enable the decision support for a green nudge.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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