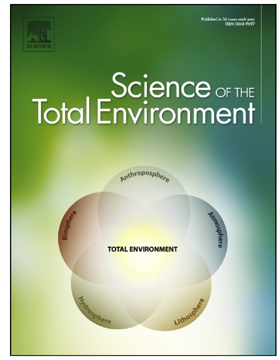
Accepted Manuscript



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PII: S0048-9697(18)34976-3
DOI: https://doi.org/10.1016/j.scitotenv.2018.12.131
Reference: STOTEN 29965

To appear in: *Science of the Total Environment*

Received date: 15 October 2018
Revised date: 8 December 2018
Accepted date: 9 December 2018

Please cite this article as: Marina Mistretta, Paola Caputo, Maurizio Cellura, Maria Anna Cusenza , Energy and environmental life cycle assessment of an institutional catering service: An Italian case study. Stoten (2018), https://doi.org/10.1016/j.scitotenv.2018.12.131

Energy and Environmental Life Cycle Assessment of an institutional catering service: An Italian case study

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Abstract

Food production is recognised as one of the major drivers for global environmental pressure. In the last years, changes in consumption models result in an increasing population consuming food out of home that pose the catering service sector at the centre of the European Union policies aimed at improving the environmental sustainability of the food sector. In this framework, better technical knowledge on the environmental impacts of catering service is essential in order to identify potential actions towards a more sustainable food sector. This article presents an environmental assessment of a school catering service operating in Italy and delivering approximately 2,518,128 meals per year. Starting from primary data on the amount of each food consumed in the catering service examined, we perform an environmental analysis of an equivalent meal ready to be consumed in the schools canteens by using the Life Cycle Assessment methodology consistent with ISO 14040 standard. The system boundaries include food and tableware production, food transport, food storage and cooking and waste treatment. Due to a lack of primary data tableware production, food storage, cooking and waste treatment are modelled using literature data or models.

The results of the analysis show that the food production phase is relevant to almost all assessed impact categories (contribution higher than 65%). The exception is represented by photochemical oxidation impact categories in which the larger impact is linked to the transportation phase. The environmental impacts associated to the tableware production, food storage and cooking are relevant to global warming and global energy requirement (contributions higher than 7%).

The scenario analysis of potential actions aimed at reducing the environmental impacts of the catering service shows that, to obtain a more sustainable food sector, strategies must be implemented along the entire food supply chain and considering a wide range of environmental impact categories.

Keywords: Institutional catering, Food energy consumption, Food supply chain, Life cycle assessment

1. Introduction

The food system is a major consumer of energy and emitter of greenhouse gases and air pollution (European Commission, 2014). In European Union (EU) the amount of energy necessary to cultivate, process, pack and bring food accounted for 17% of the gross energy consumption in 2013, equivalent to about 26% of the EU's final energy consumption that same year (Boyano et al., 2017). Moreover, it is responsible for around 20-30% of environmental impacts caused by consumption in the EU in most impact categories (European Commission, 2008; European Environment Agency, 2012). In particular, the sector is one of the leading causes of land-use change (and subsequent biodiversity loss), climate change, water scarcity/pollution, soil degradation, eutrophication, acidification and toxic impacts on human health and the environment and waste generation (European Commission, 2014, 2008). For example, Ivanova et al. (2017) show that food is a significant source of household greenhouse gas emissions in EU, with contributes ranging from 11% to 32% across regions. Then, the food sector plays a key role in the context of the EU energy and climate targets defined in the 2030 Framework for climate and energy (European Commission, 2013) and in the Roadmap 2050 (European Commision, 2012) and in general in the efforts aimed at achieving a more sustainable economy.

In the last years, within the food sector, the catering service has gained a growing importance since population worldwide is increasingly consuming food out of home (Schaubroeck et al., 2018; Sel et al., 2018)

Traditionally, catering has been divided into the “cost food service sector” or “contract catering”, which refers to non-profit or institutional catering, including workplace canteens, hospitals and schools (Davis et al., 2008), and the “profit sector” which refers to the profit-orientated establishments such as restaurants, fast-food chain outlets, cafes, takeaways, pubs, leisure and travel catering outlets (Bourlakis and Weightman, 2003).

Companies, public authorities, schools, universities, retirement homes, hospitals and prisons are all increasingly relying on contract catering (Food Service Europe, 2014; Orlando et al., 2018). In 2014, the contract catering industry had an annual turnover of approximately €24 billion and approximately 33% of firms or collective organisations in the EU had a contract with a catering company. The sector employed 600,000 people all over Europe and delivered approximately 6 billion meals each year (Food Service Europe, 2014). The most important sectors (in terms of purchase volume and value) in EU are: health/welfare (42.7% of the total meals served), education (31.4% of the total meals served) and business & industry (17.8% of the total meals served) (Food Service Europe, 2014).

Due to its significant size and economic value, the catering sector could play a key role in reducing the energy and environmental impacts linked-to the food sector. In particular, catering services has been identified as one of the sector that can provide significant environmental improvement in the public sector since it accounts for a high share of public purchasing and presents substantial improvement potential for environmental performance (Boyano et al., 2017). Public authorities, by using their purchasing power to choose environmentally friendly goods (Green Public Procurement (GPP)), can provide an important contribution to sustainable consumption and production.

The scientific literature in the field of food LCA has increased more than ten times during the last 15 years (Nemecek et al., 2016). An increasing number of studies in the literature addresses the environmental assessment of individual food products. For example, Berlin (2002) performed an LCA of Swedish semi-hard cheese; Del Borghi et al. (2014) analysed the environmental sustainability of tomato products supply chain; Djekic et al. (2014) applied an LCA to dairy products; Longo et al. (2017) compared the life cycle environmental impacts linked organic and conventional apple supply chains. Other LCAs focused on basckets of products, like Notarnicola et al. (2017) and Castellani et al. (2017).

However, as highlighted by Fusi et al. (2016) there is currently scant information on the environmental impacts of the catering sector. In the literature examined, few studies assess the environmental impact linked to it. Moreover, the majority of previous studies only considers specific issues or partial stages of the catering services instead of the catering system as a whole (Cerutti et al., 2018). For example, Fusi et al. (2016) address the impact assessment associated with the preparation of pasta and compared different cooking technologies generally adopted in the catering services. Caputo et al. (2017) develop a tool called Food Chain Evaluator (FCE), to evaluate the non-renewable energy, productive land and productive cost associated with food production in institutional catering in the school sector in the Lombardy Region (Northern Italy). Ribal et al. (2016) develop a model to identify the optimal menus for school, taking into account nutritional, climate change and economic aspects.

Based on our knowledge, only two studies perform an environmental analysis of a whole catering service, i.e. Cerutti et al. (2018) and Jungbluth et al. (2016), however both studies focus only on the global warming potential impact category.

In detail, Cerutti et al. (2018) assess a set of procurement policies aimed at reducing the GHG emissions of public catering in order to provide scientific guidance to public administrations and suppliers. The case study focuses on the full school catering services of the city of Turin (Northern Italy). The impacts are assessed with reference to an average meal (FU) calculated according to the standard menu. The phases included in the system boundaries are production, transport, cooking and waste from packaging. From the study, it can be seen that there is a global warming potential of 1.67 $kgCO_{2eq}$ per average meal.

Jungbluth et al. (2016) analyse the methodological issues for the application of the LCA to assess the global warming potential of a catering service (public or otherwise) in Switzerland. The FU is an average meal. The system boundaries include the production, processing (e.g. refrigeration), packaging, transport of food items to the canteen and the operation (meal preparation at the canteen, cooling, cooking and food waste disposal). The study shows that an average meal served in the canteen has a global warming potential of about 4.1 kg CO_{2eq}.

Achieving a more sustainable catering sector requires an assessment of the associated energy and environmental impacts in order to identify the hot spots in terms of energy and environmental burdens. Moreover, an ex – ante evaluation of potential improved scenarios could be useful in identifying the most effective strategies to increase its sustainability (Beccali et al., 2007; Giordano et al., 2014).

In such a context, Life Cycle Assessment (LCA) (ISO, 2006a, 2006b) represents a scientific methodology that helps in assessing the whole food supply chains (from the resource extraction to the end-of-life treatment) in order to achieve environmental sustainability goals, to support the identification of sustainable solutions for global food challenges (Notarnicola et al., 2016), and to identify options aimed at improving the environmental performance of the food sector (Filippini et al., 2018; Longo et al., 2017).

In detail, three distinct stakeholder groups could benefit from using LCA as a decision support tool (Cellura et al., 2012):

- Producers: to improve the environmental performance of a productive system;
- Consumers: to orient purchasers;
- Policy-makers: to inform and direct long-term strategies.

The extension of the assessment to the whole supply chain enables the identification of “where” and “how” the resources are consumed and the emissions occur (Cellura et al., 2012). The life-cycle thinking approach applied to assess a wide range of environmental issues can ensure that environmental impacts throughout the life-cycle are viewed in an integrated way and, consequently, that they are not just shifted from one step to another or from an impact category to another (Ardente et al., 2006; Beccali et al., 2003; Cellura et al., 2018)

This article reports on an LCA carried out to assess the energy and environmental impacts of a school catering service in the Lombardy Region (Northern Italy) and to identify the hotspots along the food supply chain. The assessment is based on real data of the amount of each food items consumed by the investigated catering service. Moreover, a scenario analysis integrated with the LCA methodology is performed, in order to identify potential environmental improvements to the examined catering services from a life cycle perspective.

2. Methods: Life Cycle Assessment

2.1 Goal definition

LCA is a useful tool for assessing resource use (energy and raw materials) and environmental burdens related to the full life-cycle of products and services. In this paper, we apply an attributional LCA approach according to the international standards of series ISO 14040 (ISO, 2006a, 2006b). The goals of the study are:

- to assess the energy and environmental impacts (eco-profile) of institutional catering in the school sector in Lombardy following a life cycle approach;
- to identify the hotspots of impacts along the food supply chain;
- to identify potential environmental improvement in institutional catering by analysing different scenarios from a life cycle perspective.

2.2 Scope definition

The study presented here refers to a rural and urban district of municipalities in South-West of Lombardy, referred to hereafter as Abbiatense, after the name of the main town in the area (Abbiategrasso). In the municipalities of Abbiatense, the school catering service investigated serves 2,518,128 meals per year in nursery, primary and secondary schools (Caputo et al., 2017). The catering service examined adopts the deferred system, in which the food preparation and cooking are carried out in centralised kitchens, from which the prepared meals are distributed to consumers (schools). The adopted cooking method is the cook-warm chain, i.e. the food is distributed at a temperature of 65 °C (to avoid the risk of microbial growth) and the consumption should occur within 2 hours of cooking (Fusi et al., 2016). Regarding serving, different options are adopted in the different schools within the analysed district: disposable tableware, washable dishes, or compostable dishes. In all schools, tap water is consumed and served in washable plastic or glass jugs and washable cutlery.

2.2.1 Functional unit and system boundaries

The function of the system product investigated is to provide an equivalent meal ready for the consumption in the canteens. The equivalent meal is defined as the ratio between the amount of all the foods consumed and the number of meals served in a year in the examined school catering service. Consequently, the functional unit (FU) selected as reference for the LCA is an equivalent meal served at the school canteens of Abbiatense (for further details, please refer to Caputo et al., 2017)). Considering the function chosen, the selected mass-based FU is the most suitable unit to represent the mean composition of the school catering menus over a school year (Sonesson et al., 2017). In the cases of function focused on the nutrients supply (protein content or caloric energy), other FUs based on the contribution of each food product to provide the established nutritional function are more suitable.

According to the goals of the LCA, the system boundaries include the following phases (Fig.1):

- Food and tableware production, including raw materials and energy supply in the agricultural phase and in the food processing phase.
- Food transport, including transport from the production sites to the central kitchen, and transport from the central kitchen to the school canteens.
- Food storage, including the energy consumption (electricity) for storing the food in refrigerators and freezers.

- Food cooking, including the energy (electricity and heat) consumed in the cooking phase;
- Waste treatment.

The impacts linked to food production are based on real data on the amount of each food consumed in one year in the investigated school catering services inferred from Caputo et al. (2017). As the energy consumption from the processing phases (storage and cooking phases) is missing, it is estimated using literature data or models (Canals et al., 2007).

The cleaning cooking appliance phase and the water consumed during the meal preparation are not accounted for, due to a lack of data. The electricity consumed in the school canteens is not accounted for because it is beyond the scope of the study and often available only as aggregated data for all the electric end uses (lighting, appliances and office air conditioning).

The impacts arisen from the tableware production are estimated based on literature studies (Cerutti et al., 2018; Fieschi and Pretato, 2017). In detail, it is assumed that disposable tableware are made of petroleum-based plastic, the compostable ones by Polyactide and finally the washable ones by Melamine Resin.

Due to a lack of information about the percentage of schools using disposable tableware, washable or compostable dishes, it is assumed that they are used in equal proportions in the school canteens examined. Moreover, according to Fieschi and Pretato (2017), for the disposable tableware the treatment in landfill (55%) and incineration (45%), it is assumed. While for compostable and washable tableware, the treatment in a compost plant and in a landfill, respectively, is considered.

Finally, we carry out a scenario analysis in order to identify, for each life cycle phase, potential environmental improvements of the examined catering service considering a life cycle perspective.

(FIGURE 1 HERE)

2.2.2 Impact assessment methodology and impact categories and data quality

The life cycle impacts are calculated using SimaPro software[1]. The characterisation models used are the Cumulative Energy Demand) method for the Global Energy Requirement estimation (Frischknecht et al., 2007), and the Environmental Product Declaration (EPD) characterisation factors for the environmental impacts assessment (EPD, 2016a). In detail, the assessed energy and environmental categories are:

- Global Energy Requirement ($MJ_{primary}$);
- Acidification (kg SO_{2eq});
- Eutrophication (kg PO_{4eq}^{3-});
- Global Warming (kg CO_{2eq});

[1] https://simapro.com/

- Photochemical Oxidation (kgC_2H_{4eq}).

The eco – profiles of foods are based on the Ecoinvent 3 database (Wernet et al., 2016), on environmental product declarations or certifications[2] and on the LCA food database (Nielsen et al., 2003). The eco – profiles of energy sources and transportation are based on the Ecoinvent 3 database (Wernet et al., 2016).

2.3 Life cycle inventory

The inventory analysis is performed to quantify the environmental significance of the input and output of the examined system, by means of mass and energy balances of the selected FU. In the following sections, we describe the examined catering service, the data collection and the assumption made to model the life cycle phases within the selected system boundaries and to perform the scenario analysis. In detail, in section 2.3.1, the we illustrate the "Baseline scenario", while in section 2.3.2 they describe the investigated configurations in the scenario analysis.

2.3.1 Baseline scenario

The quantity of each food included in the equivalent meal is inferred from Caputo et al. (2017). Table 1 shows the amount of each food within the examined equivalent meal and the source of the eco-profiles used.

(TABLE 1 HERE)

In the baseline scenario, all the agricultural products are produced according to conventional agricultural practices. The transportation distance for each food item is calculated, depending on current food procurement (local surveys and typical origins of food consumed in Italy), and the distances between the food production site and the central kitchen and the central kitchen and the served schools. The transportation distance between the central kitchen and the schools is estimated to be 10 km. In the transportation phase, of 16 – 32 t capacity and trucks with refrigerated container in cooling mode (temperature between 0°C and 20°C) and in freezing mode (temperature between -35°C and -18°C) are considered, based on the temperature storage needed to guarantee the safe condition of each food item.

In the food storage phase, the energy consumption for food storage in refrigerators and freezers in the central kitchen is assessed, based on the author's assumption and literature studies (Canals et al., 2007), because real data collected is not sufficiently complete and reliable. In detail, depending on the product type, it can be stored chilled or frozen. According to Canals et al. (2007), the energy consumption for cooled products is 0.06 MJ/(l*day), while for frozen products 0.18 MJ/(l*day). For each food items, a maximum of 20 days of storage it is assumed. The electricity consumption for food storage equals 0.261 kWh.

With regard to the cooking phase, it is assumed that the food is cooked on gas hobs (natural gas) and in electric ovens. The energy consumption for cooking on hotplates (hobs) and roasting/baking in the oven is calculated by using the

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[2] http://www.environdec.com/

models proposed by Sonesson et al. (2003). As Sonesson et al. (2003) provided only data for electric appliances, the direct energy consumed by gas hobs is estimated considering an energy use ratio of gas hobs/electric hobs equal to 1.51 (Fawcett et al., 2005).

The electricity use for cooking on hotplates, E_{C_hp} is calculated as in the following Equation 1 (Sonesson et al., 2003):

$$E_{C\_hp} = E_{HU} + E_{MT} + E_{HP} \tag{1}$$

Where:

E_{HU} = Energy for heating the water to the boiling point;

E_{MT} = Energy for maintaining the temperature of the water at the boiling point;

E_{HP} = Energy for heating the product.

The electricity use for food preparation in an electrical oven E_{C_eo} is calculated as in the following Equation 2 (Sonesson et al., 2003):

$$E_{C\_eo} = E_{HUo} + E_{MTo} + E_{RTo} + E_{EWo} + E_{TPo} \tag{2}$$

Where:

E_{HUo}= Energy for heating the oven to the desired temperature;

E_{MTo} = Energy for maintaining the temperature in the oven;

E_{RTo} = Energy for raising the temperature of the food to a level when it can be considered ready to eat;

E_{EWo} = Energy for the evaporation of the water;

E_{TPo} = Energy for thawing, if frozen products are prepared.

The electricity consumption for food preparation in electric ovens is 0.060 kWh, while the energy consumption for cooking on natural gas hotplates is 0.649 kWh.

The energy and environmental impacts linked to the electricity consumption for storing and cooking are calculated according to the Italian electricity mix from the Ecoinvent 3 database (Wernet et al., 2016). Whereas, the impacts which relate to gas consumption are calculated taking into consideration the production of heat from natural gas from the Ecoinvent 3 database (Wernet et al., 2016).

2.3.2 Description of the alternative scenarios for the examined institutional catering service

In order to identify potential energy and environmental improvement for institutional catering, we define and analyse different scenarios evaluating different actions, which refer to the examined life cycle phases. We assess the energy and environmental impacts of each scenario through the LCA methodology and compare the results obtained with those of the baseline scenario in order to highlight the potential achievable improvement. In detail, the following scenarios are analysed:

- Scenario 1 aims at identifying how the adoption of different agricultural practices and the local provision of food can reduce the energy and environmental impacts of the institutional catering service examined. Then, in the food production phase, we assess the energy and environmental impacts, which relate to organic rather than conventional agriculture. Due to a lack of data, a shift to the exclusive use of organic food cannot be taken into account. The following food items are modelled taking into account organic agriculture practice: bread, potatoes, salad, tomatoes, milk, rice, and yogurt. The environmental impact associated with organic milk and yogurt production is inferred from the EPDs of these products (EPD, 2015b, 2016e). The eco-profiles of organic bread, potatoes and flour are derived from Ecoinvent 3. Finally, the input data for the modelling of organic rice and salad are taken from Caputo et al. (2017). With regard to the food provision (distance from food production site to the centralised kitchen), it is assumed that, except for some fruits and ingredients, such as orange, tangerines, bananas, olive oil, the food is produced in Lombardy or in the neighbouring regions (according to a survey about the main production and distribution centre of food in Italy). The other life cycle phases are unchanged compared to the baseline scenario.
- Scenario 2, defined in order to investigate the potential environmental improvement, which could be achieved by adopting different cooking technologies, in respect of that adopted in the baseline. In detail, this scenario assumes that the food cooking occurs on gas hobs and ovens. The food production and transportation phases are unchanged compared to the baseline scenario.
- Scenario 3, defined in order to assess the potential energy and environmental improvement, which could be achieved by substituting the electricity consumed from the national electric grid with electricity produced by renewable energy technologies. In detail, in this scenario, it is assumed that the electricity, consumed for food storage and food cooking in an electric oven, is generated locally by photovoltaic (PV) panels. The eco-profile of the electricity generated from PV panels is derived from Ecoinvent 3. The other life cycle phases are unchanged compared to the baseline scenario.
- Scenario 4, defined in order to identify the energy and environmental improvement, which could be achieved by substituting the material of the tableware used in the catering service;
- Scenario 4, in which we combine the strategies considered in the previous scenarios, in order to assess the overall potential environmental improvement, which could be achieved in the institutional catering service examined, compared to the baseline scenario.

The main characteristics of the baseline and the examined scenarios are recapped in Table 2.

(TABLE 2 HERE)

3. Life cycle impact assessment and discussion

The life cycle impacts on global energy requirement and the environmental impacts of the baseline scenario are detailed in Table 3; the contribution of each life cycle phase is illustrated in Fig.2.

Global energy requirement is 23.6 $MJ_{primary}$, of which 66% comes from non-renewable energy source consumption.

Food production involves the highest share of overall global energy requirement (about 66%), of which about 54% is from non-renewable energy sources. With regard to the other life cycle phases, storage accounts for 10.4% of the total global energy requirement, cooking for 7.4%, transportation for 5.6%, tableware production for 10.7% and waste treatment for 0.03%.

(TABLE 3 HERE)

The global warming of the catering service examined is 1.43 $kgCO_{2eq}$. The production phase has the greatest impact (69%), while transport, storage, cooking and tableware production are responsible, respectively, for about 6%, 10%, 7% and 8% of the overall global warming (Fig.2). Finally, waste treatment presents contributions lower than 0.4% in all the impact categories examined.

The food production phase accounts for the greatest impact also in acidification (86%), eutrophication (89%), whereas in the photochemical oxidation impact category the highest contribution is associated with transportation (67%) (Fig.2). These results highlight that a proper environmental assessment should include a wide range of environmental categories, as according to Notarnicola et al. (2015) the environmental burdens of the agricultural phase of the food supply chain are also related to eutrophication, acidification and toxic emissions.

In order to increase the environmental sustainability of the catering service and in general of the food sector, it is important to identify strategies aimed at reducing the impacts of food production. However, non-negligible improvement could be obtained also from the other life cycle phases in specific environmental categories, for example in photochemical oxidation.

Fig.3 shows the contribution to the examined impact categories of the production stage for each food group considered in the baseline scenario. In detail, the food items are grouped into “meat, fish products”, “vegetables”, “fruits”, “pasta, bakery and grain mill products”, and “dairy and egg products”. With regard to the production stage, the “meat, fish products” group represents 12% of the equivalent meal, and its share accounts for more than 45% in all the examined impact categories. The reduction in the consumption of meat and fish products could reduce the energy and environmental impacts of the institutional catering. However, this aspect is somewhat controversial, as the main function of the food is to provide an optimum supply of nutrients through a full and varied diet, then any changes in the menu have to be done adopting a multidisciplinary perspective that includes both environmental and nutritional parameters. New menus should be defined in order to identify the alternative quantity of each food needed to balance the reduction of meat.

(FIGURE 2 HERE)

Concerning the global warming, the comparison with the LCAs on catering service available in the literature (Cerutti et al., 2018; Jungbluth et al., 2016) highlights that the result of the baseline scenario is consistent with Cerutti et al. (2018), in which the global warming potential of an average meal is 1.67 kg CO_{2eq}. But significantly different than the result obtained by Jungbluth et al. (2016), in which the global warming potential of an average meal is about 4.1 kg $CO_{2eq.}$ The discrepancy in the results could be related to the fact that the catering service examined in Jungbluth et al. (2016) it is not exclusively for schools and then the average composition of the menu could be different, including food items usually not served in school canteens, like wine and coffee. In fact, according to Jungbluth et al. (2016) in the product group of beverages, coffee and wine are responsible for a relevant share of environmental impacts.

Concerning the contributions of the life cycle phases, the results are similar in the three studies. In detail, the food production and processing are the phases responsible for the highest contributions to global warming, accounting for 78% in Cerutti et al. (2018) and for 58% in Jungbluth et al. (2016) and for 74% in this study. The contribution of transport is similar, accounting for about 6%. Differences are obtained for the cooking, storage and waste management phases maybe related to the fact that in this study the missing data is estimated using literature data or models, while both Cerutti et al. (2018) and Jungbluth et al. (2016) refer to primary data. Then, to increase the reliability of the assessment is of paramount importance to use primary data collected in the canteens to model the whole life cycle of the catering service. The relative impacts of meat are also similar in the three studies, 51% in Cerutti et al., (2018), 48% in Jungbluth et al. (2016) and 63% in this study.

(FIGURE 3 HERE)

Table 4 shows the percentage variations of the energy and environmental impacts in each assessed scenarios, in comparison with the baseline one.

(TABLE 4 HERE)

The analysis shows that, in scenario S1, the adoption of different agricultural practices and the local provision of food, which involves reduced transport distances, enables a reduction in the impact on cumulative energy demand, the global warming and the photochemical oxidation impact categories. However, a detailed analysis highlights that the most significant reduction of impacts comes from the adoption of the local provision of food practice. In fact, the adoption of organic agriculture practices is responsible for the increase in some examined impact categories. In particular, the impact of food production increases by about 4% in acidification, 3% in eutrophication and decreases by 5.1% in photochemical oxidation and 2.3% in global warming if compared to the baseline scenario, whereas the impact on cumulative energy demand decreases by 0.1%. A detailed analysis of the impact on cumulative energy demand reveals that non-renewable energy demand decreases by about 1.5% while the renewable energy demand increases by about 1.6%.

A further analysis of the food production phase was carried out in order to show the detailed contribution to the impact of foods produced using organic agriculture practices. The analysis highlights that, compared to conventional agriculture practices, organic yogurt production involves an increased impact in almost all the examined impact categories with the exception of photochemical oxidation, organic milk production in acidification and eutrophication and flour in acidification and eutrophication impact categories. On the other hand, the other organic foods (bread, potatoes, lettuce, tomatoes, rice) involve a reduction of impacts in all the examined impact categories.

Different source of data are used to assess the energy and environmental impacts of the production of the different food items. For example, the environmental impacts of milk and yogurt production, both conventional and organic, are inferred from the EPDs, while the impacts of bread, potatoes, lettuce, tomatoes and rice, both conventional and organic, are assessed through the LCI of the Ecoinvent database (Wernet et al., 2016). The products modelled starting from the Ecoinvent Database present better environmental performance when are produced by means of organic practices instead of conventional ones in all the examined impact categories (Table 5). Instead, the product modelled using the EPDs, have worse energy and environmental performances when they are produced by means of organic agriculture (Table 5). The use of secondary data involves uncertainty in a LCA study significantly.

(TABLE 5 HERE)

This essentially occurs because their accuracy and reliability, and their collection method may not be known (Reap et al., 2008). This issue is amplified when different sources of secondary data are used because each of them is characterized by a different level of data quality. Thus, to limit as far as possible the number of data sources is highly recommended. Moreover, the development of more complete databases is needed in order to obtain robust conclusions and recommendation.

With reference to the transportation phase, the local provision of food enables the impact in all the examined impact categories to be reduced consistently (more than 65%) with the exception of the photochemical oxidation impact category in which the reduction is negligible (about 1%), if compared to the baseline scenario. The local provision of food is thus a viable strategy towards sustainable food consumption and could be a practice that a municipality can adopt to improve its climate performance for example in the context of the Covenant of Major Initiative (European Union, 2010) or as GPP criteria (European Commission, 2016). However, the effect of local provision of food on the whole life-cycle impacts is quite limited, ranging from -0.8% (for the photochemical oxidation) to -4% (for global warming).

The substitution of the electric oven with a natural gas oven (S2) increases the impact on the global energy requirement, due to the higher consumption of energy when cooking in a gas oven compared to an electric oven. In this scenario, the impact on global energy requirement of the cooking phase increases by about 40% if compared to the base case. The contribution on the other impact categories shows a decrease ranging from 22% (for the global warming) to 61% (for eutrophication). These results are essentially due to the better eco-profile of natural gas when compared with the Italian electricity mix.

In the S3 scenario, the adoption of electricity generated from renewable energy sources (solar photovoltaic in the examined scenario) enables a reduction in all the impact categories examined. In detail, the impacts relating to the food storage and cooking phases decrease by 33% in cumulative energy demand, 65% in acidification, 49% in eutrophication, 58% in global warming and 55% in photochemical oxidation, when compared to the baseline scenario. These results are essentially due to the substitution of the electricity from the grid (Italian electricity mix) with electricity generated by PV panels for food storage and roasting/baking in an electric oven. The environmental benefits referred to the full service are small. However, they remain significant for the global warming and global energy requirement, in which the impacts decrease, respectively, by 10% and 6% compared to the baseline scenario. In this situation, the use of electrical appliances coupled with renewable energy resources can significantly reduce the energy and environmental impact of the catering service. It could be a viable practice to reduce the environmental burdens of the catering services and a key strategy in the current energy and climate policy of the European Union (e.g. Covenant of Majors, 2030 Energy and climate framework (European Commission, 2013), Energy Roadmap 2050 (European Commission, 2018))

In the S4 scenario, the adoption of bio-based tableware decreases the impact on global energy requirement related to the tableware production and end of life treatment of about 7%, however the improvement referred to the whole life cycle impact is -1%. The environmental contributions of tableware production and end of life treatment decrease in almost all the examined impact categories with the exception of eutrophication, in which the impact increases by 19%. In global warming and photochemical oxidation, the impacts decrease of about 45%, while in acidification of 26%. The environmental benefits are small (lower than 0.5%) if they are referred to the whole supply chain.

Finally, in scenario S5, although the combination of the strategies, examined one by one in the other scenarios, results in a reduced impact on global energy requirement (-10%), acidification (-2%), global warming (-16%) and photochemical oxidation (-5%), the impact on eutrophication increases of 1% when compared to the baseline scenario. This outcome demonstrates that, in moving towards more environmentally sustainable institutional catering and, more in general, a more sustainable food and drink sector, strategies should be implemented along the whole food supply chain and the assessment should include a wide range of environmental impact categories.

The life cycle contribution analysis of each investigated scenario highlights that food production remains the most significant life-cycle phase, since it involves the highest contribution in all the examined impact categories with the exception of photochemical oxidation (Fig.4). Then, strategies to reduce the impacts of this phase must be implemented. Food storage and cooking represents a non-negligible contribution on global energy requirement and global warming. The highest contributions are observed in Scenarios 1 and 2, in which the overall share is ~~of~~ about 20% on primary energy consumption and 17% on global warming. The lowest impacts occur in Scenarios 3 and 5 (about 15% on primary energy consumption and 8% on global warming). This is essentially due to the consumption of electricity generated by PV systems, instead of electricity from national electric grid. In the other examined impact categories, food storage and cooking contribute less than 6% in all the examined scenarios.

Food transportation accounts for more than 70% in the photochemical oxidation impact category and less than 7% in the other ones in each examined scenario. Tableware production contributes for about 10% in global energy requirement and global warming in all the examined scenarios, and it presents shares lower than 6% in the other impact categories.

(FIGURE 4 HERE)

4. Conclusions

This paper presents a LCA of a catering service aimed at identifying the related eco-profile and the life cycle phases responsible for the larger contributions. Moreover, we have analysed different scenarios in order to identify potential strategies to improve the environmental sustainability of the catering service and of the food provision in general. The case study is a school catering service operating in the North of Italy.

The results of the LCA confirms, as stated in the literature examined, that the food production stage provides the highest contribution in almost all the categories examined (greater than 70%).

Therefore, in order to achieve a more sustainable food sector, in the context of the EU climate and energy targets, strategies aimed at reducing the impact of food production are crucial and should be the first area of intervention in order of priority, in the food supply chain. Among the food categories consumed in the examined canteens, meat and fish products represent the largest share of the examined impact categories. Then, although this item is not investigated in the presented paper, the reduction in meat consumption, which is compatible with the nutritional requirements of a balanced and varied diet, can make a significant contribution towards improving the environmental sustainability of the school catering service.

Considering the high relevance of the food production phase, in order to obtain reliable environmental assessment, it is of paramount importance to use primary data about the amount of food items consumed. Moreover, further efforts are necessary in the development of more complete databases on foods production chains in order to improve the robustness of the analyses and consequently of the conclusions and recommendations.

The second main area of intervention is represented by food storage and cooking phases. The energy used to both cook and store food (heat and electricity) represents an important share of the overall impact on global energy requirement and global warming. The environmental improvement of these life cycle phases can be achieved more easily than during the food production stage, e.g. by consuming electricity produced by renewable energy technologies and or by purchasing highly energy efficient appliances. In particular, significant improvements are achieved in global energy requirement and global warming impact categories. Thus, coupling electricity with renewable energy sources could be a key strategy to improve the environmental sustainability of the food sector and in a wide perspective to achieve the energy and climate targets of the European Union.

Food transportation only has a high level of impact on the photochemical oxidation impact category and accounts for about 5% in the other impact categories examined. The adoption of local provision of food allows to reduce significantly the environmental impacts of the transportation phase, however the relative reduction assessed for the full catering service results in small benefits. This outcome confirms the importance of performing an ex-ante evaluation of the potential strategies aimed at improving the environmental sustainability of the different economic sectors.

Data and results from this study can provide an interesting insight into the primary energy consumption and environmental impacts associated with the catering service and a rough assessment of the environmental improvement associated with some practices.

The adoption of the LCA approach ensures a systemic accounting of primary energy consumption and other environmental impacts, like GHGs emission, linked to the food catering supply chain, avoiding the shift from one life cycle phase to another. Moreover, it allows to identify the main area of intervention and the and the most effective strategies. Public authorities and other stakeholders involved could benefit from basing the management practices and climate strategies upon scientific evidence, e.g. in the context of GPP strategies in the public catering sector.

Future research of this study should focus on the development of a simplified tool that allows to integrate environmental, nutritional and economic parameters in the choice of the menus served in the canteens.

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Fig. 1. System boundaries of the assessed school catering.

Fig.2. Life cycle energy and environmental impacts – processes contribution.

Fig.3. Baseline scenario: The contribution of the different food products to the examined impact categories.

Fig.4. Life cycle energy and environmental impacts in the investigated scenarios – processes contribution.

Table 1. Amount of food within the FU and eco-profile sources.

Food	Quantity (g/FU)	Life cycle inventory data source
Bread	52.51	Ecoinvent 3 + LCA food
Potatoes	49.52	Ecoinvent 3
Pasta	39.22	(EPD, 2017a)
Apples	38.91	Ecoinvent 3
Bananas	33.34	Ecoinvent 3
Carrots	31.94	Ecoinvent 3
Frozen vegetables	29.58	Ecoinvent 3 (savoy cabbage used as a proxy for frozen vegetables)
Fish	25.37	LCA food
Poultry meat	25.33	Ecoinvent 3
Peeled Tomato	22.89	(EDP, 2016)
Salad	19.32	Ecoinvent 3
Zucchini	18.9	Ecoinvent 3
Yogurt	18.47	(EPD, 2017b)
Fresh cheese	17.13	(EPD, 2017b)
Kiwis	16.01	Ecoinvent 3
Rice	15.71	Ecoinvent 3
Milk	15.49	(EPD, 2017c)
Pears	14.88	Ecoinvent 3
Spinach	14.13	Ecoinvent 3
Tangerines	13.71	Ecoinvent 3
Fennel	13.04	Ecoinvent 3
Olive oil	12.77	Ecoinvent 3
Oranges	12.73	Ecoinvent 3
Tomatoes	12	Ecoinvent 3
Beef	11.95	Ecoinvent 3
Fruit juice	11.81	(EPD, 2016b)
Eggs	10.17	(EPD, 2013)
Aged cheeses	9.71	EPD (fresh cheese used as a proxy for aged cheese) (EPD, 2016c)
Cauliflower	9.55	Ecoinvent 3
Pig meat	9.36	Ecoinvent 3
Flour	9.08	Ecoinvent 3
Tomato sauce	9.02	(EPD, 2018)
Onions	6.41	Ecoinvent 3
Dried legumes	5.8	(EPD, 2016d)
Baked ham	5.38	Ecoinvent 3 (pig meat used as a proxy for baked ham)
Ham	3.89	Ecoinvent 3 (pig meat used as a proxy for baked ham)
Cabbage	3.64	Ecoinvent 3
Peaches	2.96	Ecoinvent 3
Cookies	2	(EPD, 2015a)
Bresaola	2	Ecoinvent 3 (red meat used as a proxy for bresaola)
Savoy cabbage	1.92	Ecoinvent 3
Butter	0.98	Ecoinvent 3
Plums	0.96	Ecoinvent 3 (apricots used as a proxy for plums)
Apricots	0.92	Ecoinvent 3

Table 2. Main characteristic of the examined scenarios referred to the FU.

Scenarios	Production	Transportation	Storage	Cooking	Waste treatment
Baseline	**Food:** conventional agriculture **Tableware**: • 1/3 disposable material • 1/3 washable material • 1/3 compostable material	Current origin: 0.147 tkm (16 – 32 t track) 0.250 tkm (track with cooling container) 0.057 tkm (track with freezing container)	Electricity consumption for food storage: 0.261 kWh (Italian electricity mix)	Electricity consumption for food cooked in electric oven: 0.060 kWh (Italian electricity mix) Energy consumption for food cooked in natural gas hobs: 0.648 kWh	• Disposable tableware: landfill and incineration • Washable tableware: landfill • Compostable tableware: compost plant
Scenario 1	**Food:** organic agriculture for bread, potatoes, lettuce, tomatoes, rice, milk, yogurt and flour **Tableware**: • 1/3 disposable material • 1/3 washable material • 1/3 compostable material	Local origin: 0.019 tkm (16 – 32 t track) 0.094 tkm (track with cooling container) 0.020 tkm (track with freezing container)	Electricity consumption for food storage: 0.261 kWh (Italian electricity mix)	Electricity consumption for food cooked in electric oven: 0.060 kWh (Italian electricity mix) Energy consumption for food cooked in natural gas hobs: 0.648 kWh	• Disposable tableware: landfill and incineration • Washable tableware: landfill • Compostable tableware: compost plant
Scenario 2	**Food:** conventional agriculture **Tableware**: • 1/3 disposable material • 1/3 washable material • 1/3 compostable material	Current origin: 0.147 tkm (16 – 32 t track) 0.250 tkm (track with cooling container) 0.057 tkm (track with freezing container)	Electricity consumption for food storage: 0.261 kWh (Italian electricity mix)	Energy consumption for food cooked in natural gas hobs and oven: 0.731 kWh	• Disposable tableware: landfill and incineration • Washable tableware: landfill • Compostable tableware: compost plant
Scenario 3	**Food:** conventional agriculture **Tableware**: • 1/3 disposable material • 1/3 washable material • 1/3 compostable material	Current origin: 0.147 tkm (16 – 32 t track) 0.250 tkm (track with cooling container) 0.057 tkm (track with freezing container)	Electricity consumption for food storage: 0.261 kWh (photovoltaic electricity)	Electricity consumption for food cooked in electric oven: 0.060 kWh (photovoltaic electricity) Heat consumption for food cooked in natural gas hobs: 0.648 kWh	• Disposable tableware: landfill and incineration • Washable tableware: landfill • Compostable tableware: compost plant
Scenario 4	**Food:** conventional agriculture **Tableware**: • compostable material	Current origin: 0.147 tkm (16 – 32 t track) 0.250 tkm (track with cooling container) 0.057 tkm (track with freezing container)	Electricity consumption for food storage: 0.261 kWh (Italian electricity mix)	Electricity consumption for food cooked in electric oven: 0.060 kWh (Italian electricity mix) Energy consumption for food cooked in natural gas hobs: 0.648 kWh	• Compostable tableware: compost plant
Scenario 5	**Food:** organic agriculture for bread, potatoes, lettuce, tomatoes, rice, milk, yogurt and flour **Tableware**: • compostable material	Local origin: 0.019 tkm (16 – 32 t track) 0.094 tkm (track with cooling container) 0.020 tkm (track with freezing container)	Electricity consumption for food storage: 0.261 kWh (photovoltaic electricity)	Electricity consumption for food cooked in electric oven: 0.060 kWh (photovoltaic electricity) Heat consumption for food cooked in natural gas hobs: 0.648 kWh	• Compostable tableware: compost plant

Table 3. Life cycle energy and environmental impacts referred to the FU.

Impact category	**Total**
Global energy requirement ($MJ_{primary}$)	2.36E+01
Acidification (kg SO_{2eq})	1.47E-02
Eutrophication (kg $PO_4^{3-}{}_{eq}$)	5.02E-03
Global Warming (kg CO_{2eq})	1.43E+00
Photochemical Oxidation (kgC_2H_{4eq})	1.22E-03

Table 4. Percentage variations of the life cycle energy and environmental impacts linked to the scenarios investigated with respect to the baseline scenario.

Impact categories	**S1 (%)**	**S2 (%)**	**S3 (%)**	**S4 (%)**	**S5 (%)**
Global energy requirement ($MJ_{primary}$)	-3.7	3.2	-5.9	-0.8	-10.4
Acidification (kg SO_{2eq})	1.8	-0.8	-3.7	-0.2	-2.1
Eutrophication (kg $PO_4{}^{3-}{}_{eq}$)	0.9	-0.7	-2.0	2.0	1.0
Global Warming (kg CO_{2eq})	-5.1	-1.6	-9.9	-0.5	-15.6
Photochemical Oxidation (kgC_2H_{4eq})	-2.4	-0.4	-2.2	-0.3	-5.0

Table 5: Energy and environmental comparison between of food produced with conventional agriculture practices and with organic ones.

Conventional agriculture practices								
Impact category	Bread	Potato	Lettuce	Yogurt	Rice	Milk	Tomato	Flour
Global Energy Requirement	1.50E+00	3.11E-01	7.35E-02	4.81E-01	1.57E-01	1.51E-01	3.34E-02	3.44E-01
Acidification	5.40E-04	1.03E-04	2.55E-05	6.22E-04	3.72E-05	1.39E-04	1.44E-05	1.30E-04
Eutrophication	4.26E-04	1.03E-04	6.61E-06	1.89E-04	1.13E-05	8.60E-05	3.90E-06	1.05E-04
Global warming	4.61E-02	8.79E-03	3.54E-03	4.54E-02	7.08E-03	2.40E-02	2.23E-03	9.75E-03
Photochemical Oxidation	7.73E-06	2.48E-06	1.45E-06	2.27E-05	1.69E-06	1.47E-05	7.70E-07	1.62E-06
Organic agricultural practices								
Impact category	Bread	Potato	Lettuce	Yogurt	Rice	Milk	Tomato	Flour
Global Energy Requirement	1.48E+00	2.55E-01	6.40E-02	4.85E-01	1.56E-01	1.10E-01	3.69E-02	4.52E-01
Acidification	5.36E-04	1.00E-04	2.07E-05	7.89E-04	3.70E-05	4.91E-04	8.83E-06	2.10E-04
Eutrophication	4.26E-04	8.71E-05	5.07E-06	2.09E-04	1.12E-05	1.48E-04	1.95E-06	1.70E-04
Global warming	4.50E-02	6.26E-03	3.03E-03	4.67E-02	7.05E-03	1.05E-02	2.12E-03	6.57E-03
Photochemical Oxidation	7.54E-06	1.60E-06	1.21E-06	1.22E-05	1.68E-06	7.20E-06	4.68E-07	1.12E-06

Highlights:

- A from cradle to gate life cycle assessment of a scholastic catering is performed
- The analysis is based on primary data on the amount of each food consumed
- The food production phase is responsible for the highest environmental impacts
- Meat and fish products are the most impacting food"

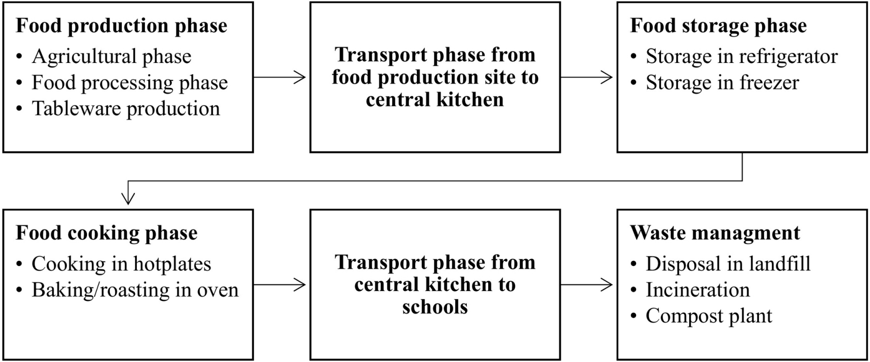
Food production phase
• Agricultural phase
• Food processing phase
• Tableware production
Transport phase from food production site to central kitchen
Food storage phase
• Storage in refrigerator
• Storage in freezer
Food cooking phase
• Cooking in hotplates
• Baking/roasting in oven
Transport phase from central kitchen to schools
Waste managment
• Disposal in landfill
• Incineration
• Compost plant

Figure 1

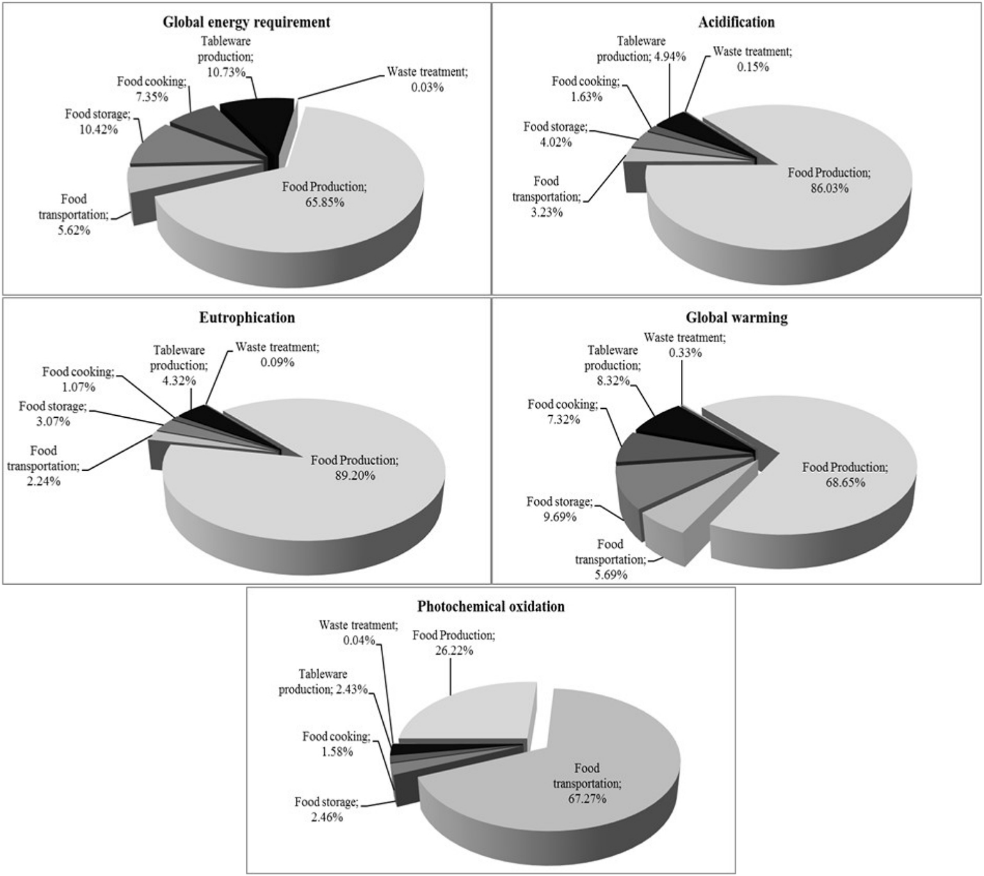
Global energy requirement
Tableware production; 10.73%
Waste treatment; 0.03%
Food cooking; 7.35%
Food storage; 10.42%
Food Production; 65.85%
Food transportation; 5.62%
Acidification
Tableware production; 4.94%
Waste treatment; 0.15%
Food cooking; 1.63%
Food storage; 4.02%
Food Production; 86.03%
Food transportation; 3.23%
Eutrophication
Tableware production; 4.32%
Waste treatment; 0.09%
Food cooking; 1.07%
Food storage; 3.07%
Food Production; 89.20%
Food transportation; 2.24%
Global warming
Waste treatment; 0.33%
Tableware production; 8.32%
Food cooking; 7.32%
Food Production; 68.65%
Food storage; 9.69%
Food transportation; 5.69%
Photochemical oxidation
Waste treatment; 0.04%
Food Production; 26.22%
Tableware production; 2.43%
Food cooking; 1.58%
Food transportation; 67.27%
Food storage; 2.46%

Figure 2

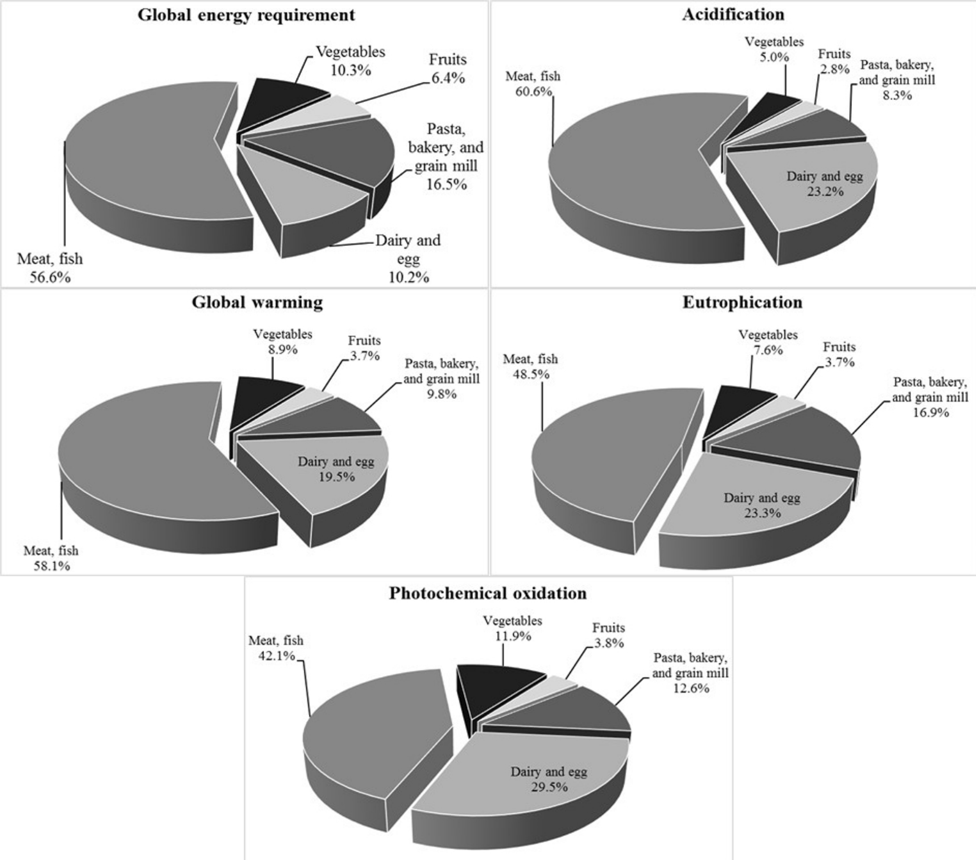
Global energy requirement
Vegetables 10.3%
Fruits 6.4%
Pasta, bakery, and grain mill 16.5%
Dairy and egg 10.2%
Meat, fish 56.6%
Acidification
Vegetables 5.0%
Fruits 2.8%
Pasta, bakery, and grain mill 8.3%
Meat, fish 60.6%
Dairy and egg 23.2%
Global warming
Vegetables 8.9%
Fruits 3.7%
Pasta, bakery, and grain mill 9.8%
Dairy and egg 19.5%
Meat, fish 58.1%
Eutrophication
Vegetables 7.6%
Fruits 3.7%
Meat, fish 48.5%
Pasta, bakery, and grain mill 16.9%
Dairy and egg 23.3%
Photochemical oxidation
Vegetables 11.9%
Fruits 3.8%
Meat, fish 42.1%
Pasta, bakery, and grain mill 12.6%
Dairy and egg 29.5%

Figure 3

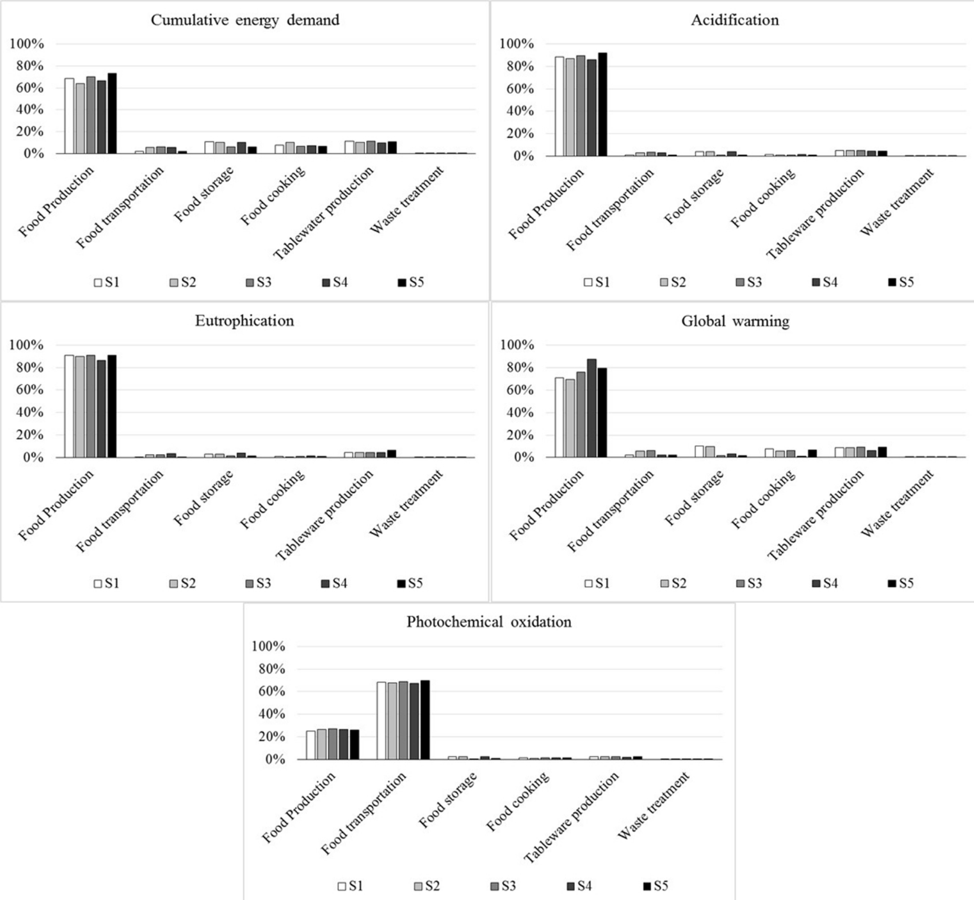
Cumulative energy demand
Acidification
Eutrophication
Global warming
Photochemical oxidation
100%
80%
60%
40%
20%
0%
Food Production
Food transportation
Food storage
Food cooking
Tablewater production
Tableware production
Waste treatment
S1
S2
S3
S4
S5

Figure 4