ENVIRONMENTAL IMPACT OF A TRADITIONAL COOKED DISH AT FOUR DIFFERENT MANUFACTURING SCALES: FROM READY MEAL INDUSTRY AND CATERING COMPANY TO TRADITIONAL RESTAURANT AND HOMEMADE

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ABSTRACT

Purpose: The environmental burdens of the same dish (a traditional hot stew with pulses and pieces of pork sausages and ham) cooked at four different production scales was analysed by LCA: (a) canned, industrially manufactured and consumed at home; (b) catering company, serving the product for schools; (c) restaurant, cooked in a traditional way and served; (d) homemade, cooked and consumed at household level.

Methods: The LCA methodology was applied following the ISO 14044:2006 guidelines. For the inventory analysis, industrial data were obtained from a ready-meals factory. Other primary data were directly obtained from the systems analysed (catering, restaurant and homemade levels). Databases (Ecoinvent, LCA Food DK, BUWAL250, IDEMAT 2001, ETH-ESU 96) were used together with SimaPro v7.3.3. For the impact assessment, the Eco-indicator 99 method and the CML 2 baseline method were used. In cases (c) and (d) different scenarios for the origin of raw materials and source of energy for cooking were considered. In level (a) an additional scenario considering a 50% reduction of food wastes was also investigated.

Results and discussion: The main contribution was meat ingredients, followed by energy consumption. Despite the higher environmental loads in transportation, the factory showed an environmental performance similar to cooking at home with gas. These results can be explained by the implementation of heat recovery systems at industrial scale. The restaurant showed the worst environmental performance. The main reason was that all the energy consumed in the restaurant (even not directly related to cooking) was attributed to the exclusive purpose of serving the food, since no other activities were carried out in the business. Consumer´s choices such as the preference for eating in a restaurant or the energy used for cooking turned out to be important differentiating factors.

Conclusions and recommendations: LCA allowed critical aspects to be identified in order to improve sustainable food production and consumption patterns. Electricity consumption and the amount of wastes sent to landfill turned out to be critical control points. In the case of complex dishes such as stews, the higher scale systems in the study (the factory and catering company), with proper energy and environmental practices, can have lower environmental burdens than small scale systems, such as homemade cooking using a ceramic-glass cooktop or consumption in traditional restaurants. To reinforce the role of education, specific programs on the need to save food and the environmental impact of dietary choices must be implemented at schools.

Keywords: LCA; cooking scale; food consumption; ready meal; catering; restaurant, homemade; environmental impact

1. Introduction

Consumer convenience increasingly demands ready meals for home consumption, while our modern lifestyle also promotes alternative ways of food consumption such as catering companies or restaurants. Public concerns about the environmental costs of foods make it necessary to compare these different common ways of obtaining a similar dish, whilst not forgetting traditional homemade cooking.

Global food production is identified as a great threat to the environment (Tukker et al. 2006; Tucker et al. 2010; Hallström et al. 2015). The food industry is one of the world's largest industrial sectors, demanding extensive energy use. Food production, preservation and distribution also contribute significantly to total CO_2 emission (Roy et al. 2009). A governmental publication in the UK (DEFRA 2006) highlighted that the food industry accounted for about 14% of energy consumption by UK businesses, 7 million tonnes of carbon emissions per year, about 10% of industrial use of the public water supply and about 10% of the industrial and commercial waste stream.

It is known that published LCA studies based on food product weight indicate that animal products, especially beef and cheese, cause 10-20 times higher environmental impact than vegetable-based products (Andersson et al 1994; Notarnicola et al 2017; Steinfeld et al. 2006; Williams et al. 2006). Also, it has been recently reported that meat and bakery products had the largest contribution to environmental impacts in an average household´s food consumption footprint in Australia (Reynolds et al. 2015).

Processed foods, with longer shelf life, are likely to show higher environmental impacts than the unprocessed ones. Several authors agree that the agricultural phase is responsible for the highest impact of the processed foods in most impact categories (Roy et al. 2009; Calderon et al. 2010, Biswas and Naude 2016). Notarnicola (2017) adds that food processing and logistics are the next most important phases due to their energy consumption and the related emissions to the atmosphere that occur through the production of heat, steam and electricity and during transport. Additionally, it was reported that the production of processed potatoes consumes 2.3% more energy than natural potato production (Ganesh 2013) and that the operations of processing meat have an impact lesser than 10% in the total carbon footprint of the product (Biswas and Naude 2016). However, this percentage of contribution was higher in the case of a ready meal (Calderon et al 2010) and equal contributions, in terms of consumed energy, were reported for the cultivation and processing steps of peach nectar production (Menna et al. 2015)

It has been highlighted that dietary choices link environmental sustainability and human health (Tilman and Clark, 2014; Halltröm et al, 2015). Published food LCAs have been analysed to quantify relationships between diet, environmental sustainability and human health. To face the so-called tightly linked diet–environment–health trilemma, the implementation of dietary solutions is considered as a global challenge, an opportunity of great environmental and public health importance (Tilman and Clark, 2014). In that work the authors remarked that, since dietary choices are influenced by factors such as culture, nutritional knowledge, price, availability, taste and convenience, solutions to this challenge will require the combined efforts of several partners (nutritionists, agriculturists, public health professionals, educators, policy makers and food industries).

Consumers are increasingly concerned about how their food is produced or where it comes from (Tukker and Jansen 2006; Weber and Matthews 2008). Also, at present, in developed countries, there is an increasing trend to replace homemade meals with industrially processed ones. The convenience food sector is expanding very quickly, expecting a global growth for the ready meals sector (Schmidt Rivera et al., 2014). In the open debate between consumers and partners, this trend is often claimed to be responsible for increasing the environmental impact of foods

(Sonesson et al. 2005). LCA studies may well provide reliable and comprehensive information to environmentally conscious policy makers, producers and consumers for making choices, selecting sustainable products, services and production processes (Roy et al. 2009). As examples, LCA was used to quantify the environmental impact of homemade meals and different convenience meals (semi-prepared and ready-to-eat), only small differences being found between them (Sonesson et al. 2005). Also, LCA was applied to analyse the impact of home-made, ready-to-eat and school lunches on climate and eutrophication (Saarinen et al. 2012). Schmidt Rivera et al. (2014) reported that the environmental impacts derived from the supply chain of a chilled ready-made meal (a typical roast dinner of chicken meat, vegetables and tomato sauce) were higher than the equivalent homemade meal.

As is common in the food processing sector, the ready meal sector causes transportation burdens when obtaining raw materials from global markets. Besides, it may be that the environmental benefits of sourcing the raw materials from countries with lower agricultural production impacts can compensate for the additional impacts of long-distance transport. Also other reasons may justify sourcing from global markets such as high demand for seasonal foods and productivity. It has been highlighted (Edward-Jones et al., 2008) that distance from source is not the only attribute that consumers associate with local food, since other important reasons are considered such as support for local producers or taste. It should be taken into account that energy use or wastage does not necessarily increase at industrial scale. In fact, at higher processing scale, less energy is consumed when cooking food in large batches compared to small scales, especially considering that heat recovery is feasible. These two factors, production scale and transport, turned out to be the key aspects that determined the best environmental option for the production of biodiesel from sunflower oil in a particular area (Sonesson et al. 2005; Schmidt et al. 2014; Iglesias et al. 2012). Size scaling relationships were previously used for LCA purposes (Caduff et al., 2012) as recommended by the ISO standard, although this information is generally still lacking in many studies.

Several LCA studies of food products have analysed the impact on the food chain of single food items, but reported LCA studies of complete dishes are still very scarce (Zufia and Arana 2008; Davis and Sonneson 2008; Calderón et al. 2010; Schmidt et al. 2014). It has been pointed out that there is currently scant information focused on the life cycle environmental impacts of convenience food, and particularly in the ready-made meals sector (Schmidt Rivera et al., 2014). The goal of this study is to analyse by LCA the environmental impacts of the same dish manufactured or prepared at four different scales (industry, catering company, restaurant, homemade) and consumed at home, at school or in a traditional restaurant. As far as we know, no other LCA studies have been focused yet on the levels of efficiency of economies of scale in the ready meals sector. Additionally, for the traditional restaurant, both long-distance and the usual local production of the raw materials were evaluated, and for the household level two different energy sources for cooking were considered. In order to check the influence of food wastes, a new scenario has been considered for the factory scale corresponding to 50% food waste reduction in relation to those initially used in this work. This reduction value was selected as published by Lundqvist et al. (2008)- and reviewed by Parfitt et al. (2010)- advocating a 50% reduction in post-harvest losses to be achieved by 2025.

In this investigation, for the impact assessment stage the Eco-indicator 99 (H) V2.05/Europe EI 99 H/A method was used. This method belongs to the LCIA endpoint methodologies in ISO. In this way, the impact categories calculated in the characterisation step quantify the contribution of each inventory flow to the damage caused directly to human health, to ecosystem health and the damage caused to resources. To additionally support the results obtained, the CML 2 baseline 2000 V2.04/World 1990 method, belonging to the LCIA midpoint methodologies, was also used.

Indicators at midpoint level are reported to be more comprehensive and to reflect higher societal consensus than aggregated endpoint indicators (Bare et al., 2003). In addition, in this work normalisation was performed to establish a common reference to enable comparison of different environmental impacts (Bare et al., 2003; Baumann and Tillman, 2004; Calderón et al. 2010; Iglesias et al. 2012; Wilfart et al., 2013).

2. Materials and methods

2.1. Goal and scope

The product under study is a traditional Spanish (Asturian) stew of broad beans with pieces of pork sausages and ham. The aim of this work was to compare the environmental loads of the dish when manufactured or prepared with different production systems and under different consumption patterns: as a ready meal dish (canned food) consumed at home and manufactured in a factory; as a dish served by a catering company and consumed in a school dining room; when cooked and served in a traditional restaurant and when cooked and consumed at home.

In the systems under study, the selected functional unit (FU) was 1 kg of finished hot product ready to be consumed.

The systems compared were as follows:

a) An industry located in Spain which produces around 8000 tons of the considered canned product per year (around 60% of its total production). This factory was previously inventoried and analysed using the LCA methodology. The following aspects were considered: production of ingredients and materials, transportation of raw materials to the factory, product processing at the factory including emissions and waste generation, transportation of final product, reheating and final consumption of the canned dish at home including waste generation (Calderón et al. 2010).

b) A modern catering company serving 5800 customers (school meals) every day. The dish under study is served approximately once per month. In this case the dish was cooked on gas in double-jacketed pans with indirect heating (bain-marie system), transported in isothermal delivery vans, reheated in an electric convection oven and served in polypropylene trays.

c) A traditional Asturian restaurant serving an average weight of 580 kg of food per month, from which around 160 kg correspond to the dish under study. The meal was prepared using large casseroles on a gas cooker. Two different scenarios were considered: long-distance transport of raw materials as in the cases a, b, and d, and local production, which is the most usual scenario in this type of restaurant (only differences in transport distances were considered).

d) Finally, homemade preparation of the dish in the traditional way was analysed. Two cooking alternatives were considered: the use of an electric glass-ceramic cooktop and the use of a gas cooker.

Outlines of the systems compared are shown in Fig. 1. They have been divided into seven subsystems:

(i) Food ingredients. The environmental loads assignable to the processes for obtaining raw materials employed as food ingredients (except water), including farming activities and the foodstuff processes. For the production of one functional unit (1 kg of finished product ready to be consumed) around 43% and 41% of the total food ingredients were pork meat cuts and pulses, respectively.

(ii) Process water. Loads assignable to the consumption of water, including water used for soaking broad beans, water employed as an ingredient, water consumption for doing the washing up with a dishwasher and wastewater treatment in a wastewater treatment plant (WWTP).

(iii) Cleaning products. Considering loads assignable to their production.

(iv) Packaging material. Corresponding to loads assignable to can production, plastics and cardboard.

(v) Solid waste management. Environmental impacts assignable to the disposal in landfill and to the recycling of solid wastes (mainly due to food remains and packaging materials). During the manufacturing stage, data regarding food wastes generated in the factory were provided directly by manufacturers and these same data were assumed to be valid for the catering company. Manufacturing food waste data were also provided directly by the local restaurant and the same values were assumed at the homemade level. At consumption level, food remains were considered to be 20% of the served food, as previously published in a generic estimate in the UK (Ventour, 2008). The materials used for packaging at the factory and catering scales (tin cans and plastic trays) were also considered as wastes. In the case of the canned dish, the tinplate used in cans corresponded to 34% of the total solid wastes generated, whereas the plastic for packaging corresponded to 15% of total solid wastes in the catering company, 19% in the restaurant and 19% at home. The management of wastes generated is detailed in Table 1. At consumption level, the recycling percentages in Spain have been applied, provided by the non-profit pro-recycling company Ecoembes (Report 2007).

(vi) Transport. For the factory and the catering company, loads assignable to transportation of raw materials and distribution of the final product were considered. In the case of the factory, the final product was transported from the factory to the central distribution centre, and then from this centre to the different regions in Spain, by lorry (>28 t). In the case of the catering company, final products were transported from the production facility to different schools. For restaurant and homemade manufacturing, only transportation of raw materials was considered. For the restaurant, two scenarios, using raw materials from imports and from local production, were distinguished.

(vii) Energy. Loads assignable to gas and electricity used. In the factory system the energy used for manufacturing the dish and the electricity consumption for heating the product at home were taken into account. In the catering system, gas consumption in the manufacturing processes and electricity for reheating the product before serving were included; in the other systems, energy consumption in the restaurant for cooking and serving the dish on the table and the energy used for cooking the dish at home were also considered. Besides, in all systems, electricity used for doing the washing up was also taken into account. The electricity mix used was the electricity mix in Spain, including imports from other countries (ETH-ESU 96).

The majority of data for the canned dish were provided by the factory under study, corresponding to annual average values (2007) obtained from previous work (Calderón et al. 2010). Other data were measured (e.g. the amount of packaging materials). The catering company and the restaurant provided detailed information about gas and electricity consumption. Physical allocation by mass was used to calculate water, cleaning products and energy consumptions and waste generation. In addition, in the case of the industry and catering company, detailed information about the distances of the delivery route was obtained. Electricity consumption at household level was calculated from electrical appliance specifications. Other transport distances were calculated using maps. A cut-off approach was used for waste recycling.

2.2. Life Cycle Inventory Analysis (LCI)

A summary of the inventory data and databases employed in this work are shown in Tables 1 and 2, respectively. None of the available databases contained all the products involved in the study, so several databases were used in order to select the entry that best describes the product in each case.

2.2.1. Limitations and assumptions

In this work, the same food ingredients were used in the four systems.

As mentioned, taking into account a study carried out in the UK at household level (Ventour 2008), the foodstuff thrown away as waste was considered to be a fifth (20%) of the total purchased. Despite of the fact that this percentage might be somewhat higher in restaurants, it should be also taken into account that food remains in the restaurant can be packed to take away. So, in this work, no differentiation was made between the foodstuff thrown away from ready-made meals and freshly cooked meals, at home, at school lunchrooms and at restaurants. It was assumed that this food waste, together with non-recycled packaging waste, went to a landfill with municipal waste (a common practice in several Spanish regions).

With the exception of the tin in the case of the canned food and the tray in that of the food served by the catering company, the rest of the packaging material system, as well as the waste management system for that packaging, were considered to be the same at both factory and catering scales.

The transport system for the raw materials was considered to be the same in all the systems compared. In the restaurant, as mentioned, a second scenario was considered in which the stew was prepared with raw materials produced locally.

It was considered that all the energy consumed in the restaurant business was used with the exclusive purpose of serving the dish to the customers. So, in this system, allocation by mass was applied by dividing the total amount of electricity and gas consumption by the kg of food served. This could be a potential source of error. However, this approach was considered to be acceptable because the restaurant was specialized in the dish here evaluated, or similar slow-cooking dishes implying comparable energy consumptions. On the contrary, when the food is served at home or school (catering scale), energy used for lighting or space heating is more difficult to allocate independently from other activities not related exclusively to food consumption.

In the restaurant and at home, raw materials were understood to have been bought in bulk with light packaging, and the pork meat-based ingredients packed in a plastic film of polypropylene (PP). In the homemade system it was assumed that no plastic bags were necessary for carrying the shopping.

The homemade dish was cooked in the traditional way, that is, with slow boiling, which meant an electric power consumption of 2100 W for 20 minutes and 1200 W for 2 hours on a glass-ceramic cooktop. In the alternative scenario, when cooked using a gas cooker, the same gas consumption as in the restaurant was assumed.

Besides, at household level, a total consumption of 10.5 liters of water was considered, from which 1.5 corresponded to the water used for soaking the broad beans and for cooking, and the rest for the process of washing-up in a dishwasher. The washing of cooking implements used for cooking 1 kg of homemade stew, and the crockery and cutlery used in its consumption, was assumed to represent 1/2 a full load in a domestic dishwasher of energy rating B. This process was considered to consume an average of 18 L of water, including rinse aid usage, and 1.6 kWh of electricity per load, as shown in equipment specifications (half for the functional unit).

Electricity and water consumption in the process of washing cooking implements were considered to be the same when the dish is consumed at home, as is the case in the homemade and factory systems. In the restaurant and catering systems, in which industrial door-type dishwashers were used, there were average annual savings of 25% in both water and electricity consumption (obtained from manufacturer´s specifications). Dishwasher detergent consumption for the washing-up process was considered to be the same in all the compared systems.

2.3. Life Cycle Impact Assessment (LCIA)

The endpoint modeling consists in characterizing the severity of the damage that is modeled by the midpoint indicator. It has been previously published that the competition between midpoint and endpoint methods has developed into coexistence, where the two approaches supplement each other since endpoint indicators in three areas of protection (human health, natural environment and natural sources) can be linked to midpoint inventory results (Hauschild et al., 2013).

Normalisation was applied to perform a comparison of different environmental impacts (Baumann and Tillman, 2004). Data bases used on line in the characterisation and normalisation steps together with the software tool SimaPro v7.3.3 are shown in Table 2.

3. Results and discussion

As can be seen in Fig. 2, some differences between scenarios can be observed. The minerals category is more affected in the factory system due to the production of the tin used for the cans. The scenarios with the highest production scale (the factory and the catering systems) showed the expected effect of reduction of the environmental impacts, as the production scale increases, in the categories respiratory inorganics, climate change, radiation and ozone layer. So, for the restaurant and homemade systems, higher environmental impacts were observed in these categories. However, an inversion occurred for the restaurant and homemade systems, and it was clearly observed that the restaurant scale turned out to be the system with the worst environmental performance in the commented categories. The rest of the categories did not show difference so marked between scenarios with the exception of minerals, already commented, and fossil fuels. The systems with the lowest consumption of fossil fuels were the factory and homemade, whereas the consumption in the restaurant was around 69% higher. Results obtained after normalisation indicated that the categories fossil fuel consumption and land use showed the maximum deviation from the reference average (see Fig. 2). They were followed by respiratory inorganics, an impact category that, according to this method, showed more clearly the great differences between the two main groups of systems, the high scale systems (factory and catering) and the small scale systems (restaurant and homemade).

As can be seen in Fig. 3, the single score calculated with Eco-indicator 99 showed that food ingredients, energy and transport were the subsystems with the highest environmental burdens. Food ingredients was the subsystem responsible for the highest contribution (around 50%) in the factory, catering and homemade systems. However, in the restaurant scale, energy consumption ranked in first place. The reason, as can be deduced from data shown in Table 1, was that natural gas and electricity consumptions were higher at this scale. At the homemade scale the energy subsystem also represented an important weight. For this reason, two different scenarios were considered as energy sources for cooking: glass-ceramic cooktop and gas cooker, thus changing electric for natural gas consumption. Fig. 4 shows that this alternative scenario (gas cooker) implied an important decrease in the respiratory inorganic category and an increase in the fossil fuels category. The total impact was lower in the case of the gas cooker.

Table 3 summarizes the most important subsystems and their contributions to the most important impact categories. Figures revealed the great significance of the subsystem of food ingredients in almost all categories, especially land use, carcinogens, acidification/eutrophication and minerals (except for the factory). In particular, production of meat ingredients is responsible for more than half the environmental burdens in the land use category and it is also very important for acidification/eutrophication. The major contribution of energy was to the respiratory inorganics and climate change categories, and that of transport and packaging materials to fossil fuels, whilst solid wastes management contributed principally to carcinogens. It is noteworthy that the highest impact in the minerals category was found for the factory system (see Table 3 and Fig. 2). As can be observed in Table 3, in all systems most of the burdens attributable to the energy subsystem were due to electricity consumption (except for the fossil fuels category), in spite of the use of natural gas for cooking in some cases. The restaurant scale had the highest electricity consumption, attributable to lighting, ventilation, space heating, cooling, sanitation, cold storage, appliances and other kitchen equipment needed at both preparation stage and consumption stage. All this energy was considered to be consumed with the only function or purpose of cooking and serving the dish.

It should be taken into account that, even though restaurants provide complementary functions such as social wellbeing and social relationships, customers ask for foods to be cooked and served. When this service is not provided, a restaurant is closed. In this traditional restaurant where data was collected, when it was closed, the electricity supply was turned off and the refrigerators disconnected, without providing additional uses or services to customers, as commonly occurs in this type of business. On the other hand, regarding the use of energy at home and at school, obviously, electricity use cannot be allocated exclusively to the food served. There are even schools where catering services are not provided or even homes where food is not served, but energy is used likewise for functions such as lighting or space heating. So data related exclusively to the use of energy due to food consumption in these two systems cannot be determined, it being assumed that it could not be allocated separately from other inherent uses at home and at school.

Regarding the transport subsystem, some differences between scales can be observed in Fig 3. Those systems at high scale, factory and catering, had a greater contribution to this subsystem. The reason in the factory scale is the complex distribution network of product transportation. As generally happens with food products, at the industrial scale, distribution was from a centralized logistics hub, causing increased environmental loads to this subsystem. However, catering distribution routes always had their origin at the point where the food was prepared and so differences in transportation in relation to the lower scale systems were quite low (see Table 1).

So, in this case, transport contribution to the single score was higher mainly because the contributions of other subsystems were lower.

The restaurant was the scale selected to analyse the contribution of local production. So, two different scenarios for transportation were considered at this scale. In the first one, the transport subsystem for food ingredients was the same as that employed in the rest of the systems, while in the second one it was assumed that the dish was manufactured with local products, so the subsystem transport was modified accordingly. Local production only allowed a small reduction in environmental impacts (lower than 10% with respect to the single score). It should be taken into account that uncertainties or even contradictory results can be found in LCA published literature when analyzing local food production versus long-distance sourcing. Moreover, it should be considered that even the term "local" could be ambiguous and used or understood in different ways, as shown (Edward-Jones et al., 2008). Since distance from source is not the only attribute that consumers associate normally with local food, but also other reasons such as support for local producers or taste, the same authors proposed the interest to integrate analysis of social issues with LCA, an issue normally lacking for nearly all food chains. Note that environmental implications derived from different farming methods have not been considered in this work.

As shown in Table 1, the amount of solid waste sent to landfill was similar for the different scales. It should be pointed out that in all cases organic matter represents more than 80% of these wastes, mainly due to the leftover cooked food that was thrown away. Packaging waste was particularly relevant in the factory system, mainly due to the use of cans. This slightly increased the amount of solid waste sent to landfill and significantly the amount of solid waste sent to recycling (see Table 1). It was reported that a key issue for improving sustainability in food production is a reduction in the amount of food waste sent to landfill (Katajajuuri et al 2014), complying to European Regulations on treatment and disposal of the biodegradable fraction of wastes. In this study the amount of waste sent to landfill would be significantly reduced by reducing the amount of leftover cooked food. Therefore, considering the factory scale, an additional scenario was imagined in which food waste at household level was reduced by 50% (since some authors have called for action to achieve this reduction level in post-harvest losses by 2025, Parfitt et al. 2010). It is supposed that, in the new scenario, the food that does not turn into waste is eaten or stored to be eaten later. This reduction in the waste generated at home meant a 35% reduction in the amount of solid waste sent to landfill. As expected, the impact categories which improved most significantly with this reduction were those most affected by the solid waste management subsystem, i.e. ecotoxicity, carcinogens and climate change. The reductions achieved in these impacts were approximately 21%, 11% and 3%, respectively. However, when the single score, which takes into account all the impact categories, is considered, the reduction achieved was just 1%. This can be explained by the fact that the most important categories in this work, i.e. land use, fossil fuels and respiratory inorganics, were almost unaffected by the solid waste management subsystem (see Table 3).

As previously published (Lloyd et al, 2007) it should be considered that research is needed to understand the relative importance of different types of parameter, scenario, and model uncertainty to determine the types of uncertainty and variability that should be included in LCA. The same authors found that, due to the complex and uncertain nature of environmental processes, more assumptions are required in the approaches used for estimating impacts than in the approaches used in inventories, focusing on process parameters.

3.1. Analysis of the impact contributions and suggestions for improvement measures

The restaurant system turned out to be the environmentally least favourable system because of the high electricity consumption in tasks other than cooking, but nonetheless necessary due to the particular requirements when the dish is consumed (meaning excessive lighting, air conditioning or heating…) in order to provide social wellbeing. Contrary to what many ordinary consumers might have expected, systems manufacturing at high scale (factory and catering systems) turned out to be the ones with better environmental performance, despite environmental loads in transportation. This can be explained by the use of gas for cooking, lower energy consumption in large batches and the implementation of heat recovery systems at industrial scales.

Bearing in mind that the few published LCA studies focusing on complete meals only considered a limited number of impacts (Sonesson et al. 2005; David and Sonesson 2008), the CML 2 baseline 2000 method was also applied with the aim of checking the validity of the results obtained and to increase the number of impact categories analysed in this work. The impact categories that showed the maximum deviation from the reference averages were the ecotoxicity of both fresh and sea water, mainly due to the contribution of the subsystem solid waste management. The other subsystems responsible for the highest environmental loads were food ingredients, transport and energy, in agreement with results obtained with Eco-indicator 99. When comparing the different scenarios, the worst results were again obtained for the restaurant system in most of the impact categories. Figure 5 shows the relative carbon footprint (CF) calculated with this method as Global Warming Potential. As expected, the highest footprint was obtained for the restaurant system, a value that is more than double of the carbon footprints obtained for the factory, catering and gas-cooking homemade systems. However, it has been estimated that, in the restaurant under study, kitchen activities consume 10% of the electricity. Additionally, data from US suggests that 73% of the natural gas consumed in restaurants is used for cooking and related activities (EIA 2003). Considering these data, the total energy consumed in the restaurant (Table 1) and the CO_2 emissions factors for electricity and natural gas, it can be concluded that approximately only a quarter of the restaurant CF is due to cooking activities. This is in agreement with the fact that approximately, only 30% of the total energy consumed by Spanish restaurants is used for cooking activities. The rest of the energy is mainly consumed for lighting, refrigeration and space heating, with percentages of 28%, 19% and 17%, respectively (data from the Community of Madrid, Spain, De Isabel et al. 2012). If only the cooking contribution was considered, the restaurant CF would be similar to those obtained for the factory and catering systems. Thus, the reason for the higher CF obtained in the restaurant system was the consideration that the served food was responsible for all the energy consumed in the restaurant, since no other activities were carried out than cooking and serving the food, differing from activities carried out at home or school.

It was previously reported (Schmidt et al. 2014) that the consumer's choice of heating method was an important differentiating factor when comparing the environmental impacts derived from the consumption of an industrial ready-made meal with its equivalent made at home. Heller and Keoleian, (2003) found that effective opportunities to enhance the sustainability of food systems still exist by changing consumption behaviour, thus gaining benefits in agricultural production, distribution and food wastage.

If they are going to change their consumption habits, consumers must have sufficient information, so accurate scientific data should be available for decision-making strategies. Jungbluth et al. (2011) reported that, despite the fact that in recent years product information has been based only on carbon footprint, this methodology may be insufficient for full environmental information to consumers, so LCA approaches might be recommended instead, provided in a simplified form. Following this line, and as shown in this work, the application of LCA methodologies may well be recommended to offer environmental food product information to consumers and partners, in a simple and understandable way.

It has been suggested that dietary change, along with technical advances in agriculture, is necessary to reduce the environmental impact of the food system (Hällstrom et al. 2015). Results shown in that work suggest that in areas with an affluent diet, dietary change can play an important role in achieving environmental improvements, with up to 50% potential reduction in GHG emissions and land use associated with current diet. These authors proposed that further studies should be carried out on the impact of meat substitutes and complements and their effects in different population groups and in different geographical locations. The final objective of such studies would be to achieve a better understanding of dietary change as a measure for a more sustainable food system (Hälltrom et al. 2015).

Considering the high energy consumption and associated environmental loads of food production, it must be pointed out that the role of education has not been sufficiently reinforced. While in developed countries with an affluent diet scholars are well aware of the need of saving water, the need to save food is not yet regarded at the same level of importance at schools It has been published that higher household economic level caused greater environmental burden than that of the less well-off household (Reynolds et al, 2015). Specific educational programs must be implemented in schools, related not only to healthy habits as at present, but also specifically focused on the awareness of the high environmental loads associated with food production and the urgent need to achieve improvements by saving food and changing prevailing dietary habits.

4. Conclusions

Life Cycle Assessment has been proved to be a useful tool, not only for identifying critical aspects in food production (an attributional LCA approach), but also for making comparisons between different manufacturing scales and consumption patterns, with the ultimate objective of achieving better environmental performances.

The main contribution to environmental impact was mainly due to meat ingredients and therefore, low-meat or vegetarian dishes would be more environmentally friendly. Energy consumption and transport were the following contributions in order of importance. More specifically, electricity saving was a critical control point in the manufacturing processes of complex dishes.

High scale systems like the ready meals industry and catering companies, with proper management of energy saving and waste reduction, can offer better environmental performance than small scale systems, such as eating out in restaurants or even cooking at home on a ceramic-glass cooktop. The environmental behavior of the homemade scale depended on the energy source used for cooking, being more sustainable the use of a gas cooker. It is necessary to take into account that portions sizes and storage time of the ready-made meals are key factors regarding the environmental performance of the products, since they influence on how much food is wasted by the consumers, parameters that have not been analysed in this study. Other aspect to be considered is that the main reason for the high environmental charges found in the restaurant scale, is that all the energy consumed in the restaurant, including energy used for lighting or heating, was allocated to the food served, because it was understood that serving dishes was the only purpose of the restaurant since no other activities were carried out in this type of business. This fact highlights the environmental interest of implementing energy-saving measurements for all energy consumptions in food service establishments.

Finally, further LCA research in this area is required to help consumers and partners to make informed choices about different food systems and food consumption patterns, with the aim of improving sustainability in the food sector. Also, regarding the need to save food and the environmental impact of dietary choices, specific educational programs must be implemented at schools.

References

Andersson K, Ohlsson T, Olsson P (1994) Life cycle assessment (LCA) of food products and production systems. Trends Food Sci Tech 5:134–138

Audenaerta, A, Cleynb, SH, Buylea M (2012) LCA of low-energy flats using the Eco-indicator 99 method: Impact of insulation materials. Energ Buildings 47:68–73

Baumann H, Tillman AM (2004) The Hitch Hiker´s guide to LCA: an orientation in Life Cycle Assessment methodology and application. Lund, Sweden: Studentlitteratur

Bare JC, Norris GA, Pennington DW, McKone T (2003) TRACI — The tool for the reduction and assessment of chemical and other environmental impacts. J Ind Ecol 6:49–78

Biswas WK, Naude G (2016) A life cycle assessment of processed meat products supplied to Barrow Island: A Western Australian case study. J Food Eng 180:48-59

Caduff, M, Huijbregts MAJ, Althaus H-J, Koehler A, Hellweg S (2012) Wind power electricity: the bigger the turbine, the greener the electricity? Environ Science Technol 46:4725-4733

Calderón LA, Iglesias L, Laca A, Herrero M, Díaz M (2010) The utility of Life Cycle Assessment in the ready meal food industry. Resour Conserv Recy 54:1196–1207

Davis J, Sonesson U (2008) Life Cycle Assessment of Integrated Food Chains - A Swedish Case Study of Two Chicken Meals. Int J LCA 13:574-584

De Isabel, J.A.,García, M., Egido C. (2012) Guide for energy audits in restaurants of the Community of Madrid. Energy Foundation of the Community of Madrid. http://www.fenercom.com

Defra. Food Industry Sustainability Strategy (FISS) 2006 Published by the Department for Environmental, Food and Rural Affairs. Defra, London. http://www.defra.gov.uk

European Commission 2010. Preparatory study of food waste across EU27. Technical report 210-054.

Edwards-Jones G, Milà i Canals L, Hounsome N, Truningerd M, Koerber G, Hounsome B, Cross P, York EH, Hospido A, Plassmann K,, Harris IM, Edwards RT, , Day GAS, Tomos AD, Cowell

SJ, Jones DL (2008) Testing the assertion that “local food” is the best: the challenge of an evidence-based approach. Trends Food Sci Tech 19:265-274.

Ganesh VR (2013) Life cycle analysis of the processed food versus the whole food (Potato). Int J Appl Sci Eng Res 2(1):70-78.

Hällstrom E, Carlsson-Kanyama A, Börjesson P (2015) Environmental impact of dietary change: a systematic review. J Cleaner Prod 91:1-11

Hauschild MZ, Goedkoop M, Guinée J, Heijungs R, Huijbregts M, Jolliet O, Margni M, De Schryver A, Humbert S, Laurent A, Sala S, Pant R. (2013) Identifiying best existing practice for characterization modeling in life cycle impact assessment. Int. J. Life Cycle Assess 18:683-697.

Heller MC, Keoleian GA (2003) Assessing the sustainability of the US food system: a life cycle perspective. Agr Syst 76:1007–1041

Iglesias L., Laca A., Herrero M., Díaz M. (2012) A life cycle assessment comparison between centralized and decentralized biodiesel production from raw sunflower oil and waste cooking oils. J Cleaner Prod 37:162-171

ISO (2006a) ISO 14040 – Environmental management – life cycle assessment – principles and framework. International Organization for Standardization, Geneva

ISO (2006b) ISO 14044 – Environmental management – life cycle assessment requirements and guidelines. International Organization for Standardization, Geneva

Jungbluth N, Büsser S, Frischknecht R, Flury K, Stucki M (2012) Feasibility of environmental product information based on life cycle thinking and recommendations for Switzerland. J Cleaner Prod 28:187-197

Katajajuuri J-M, Silvennoinen K, Hartikainen H, Heikkilä L, Reinikainen A (2014) Food waste in the Finnish food chain. J Cleaner Prod 73:322-329

Lloyd SM, Ries R (2007). Characterizing, propagating and analyzing uncertainty in Life-Cycle Assessment. A survey of quantitative approaches. J Ind Ecol 11:161-179.

Lundqvist J, de Fraiture C, Molden D (2008) Saving water: from field to fork—curbing losses and wastage in the food chain. In SIWI Policy Brief. Stockholm, Sweden.

De Menna F, Vittuari M, Molari G (2015) Impact evaluation of integrated food-bioenergy systems: A comparative LCA of peach nectar. Biomass and Bioenergy 73:48-61

Notarnicola B, Tassielli G, Renzulli PA, Castellani V, Sala S (2017) Environmental impacts of food consumption in Europe. J Cleaner Prod 140:753-765

Parfitt J, Barthel M, Macnaughton S (2010) Food waste within food supply chains: quantification and potential for change to 2050. Phil Trans R Soc B 365:3065-3081

Reynolds CJ, Piantadosi J, Buckley JD, Weinstein P, Boland J (2015) Evaluation of the environmental impact of weekly food consumption in different socio-economic households in Australia using environmentally extended input-output analysis. Ecol Econ 111:58-64

Roy P, Nei D, Orikasa T, Xu Q, Okadome H, Nakamura N, Shiina T (2009) A review of life cycle assessment (LCA) on some food products. J Food Eng 90:1–10

Saarinen M, Kurppa S, Virtanen Y, Usva K, Mäkelä J, Nissinen A (2012) Life cycle assessment approach to the impact of home-made, ready-to-eat and school lunches on climate and eutrophication. J Cleaner Prod 28:177-186

Schmidt Rivera XC, Espinoza Orias N, Azapagic A (2014) Life cycle environmental impacts of convenience food: Comparison of ready and home-made meals. J Cleaner Prod 73: 294-309

Sonesson U, Mattsson B, Nybrant T, Ohlsson T (2005) Industrial processing *versus* home cooking: an environmental comparison between three Ways to prepare a meal. Royal Swedish Academy of Sciences. Ambio 34:414-421

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (2006) Livestock's Long Shadow – Environmental issues and options. FAO – Food and Agriculture Organization of the United Nations, Rome

Tilman D, Clark M (2014) Global diets link environmental sustainability and human health. Nature 515:518-522

Tucker G, Foster C, Wiltshire J (2010) Life Cycle Analysis and Carbon Footprinting with respect to Sustainability in the Agri-food sector. IUFoST SIB.

Tukker A, Huppes G, Guinée JB, Heijungs R, Koning A, Oers LFCM, Suh S, Geerken T, Holderbeke M, Jansen B, Nielsen P (2006) Environmental Impacts of Products (EIPRO). Analysis of the Life Cycle Environmental Impacts Related to the Final Consumption of the EU-25. European Commission, JRC e IPTS, Luxembourg

Tukker A, Jansen B (2006) Environment impacts of products–A detailed review of studies. J Ind Ecol 10:159–182

Ventour L (2008) The food we waste. In: Waste & resources action programme (WRAP); ISBN 1-84405-383-0

Weber CL, Matthews HS (2008) Food-miles and the relative climate impacts of food choices in the United States. Environ Sci Technol 42:3508–3513

Wilfart A, Prudhomme J, Blancheton JP, Aubin J (2013) LCA and emergy accounting of aquaculture systems: Towards ecological intensification. J Environ Manage 121:96-109

Williams AG, Audsley E, Sandars DL (2006) Final report to Defra on project IS0205: Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities: a report to the Department for Environmental, Food and Rural Affairs. Defra, London

Zufia J, Arana L (2008) Life cycle assessment to eco-design food products: industrial cooked dish case study. J Cleaner Prod 16:1915–21

Figure Captions

Fig. 1 Outline of the systems under study

Fig. 2 Results obtained after normalisation using Eco-indicator 99. Long-distance production for raw materials was considered for all cases and glass-ceramic cooktop was considered for the homemade scenario.

Fig. 3 Single score using the Eco-indicator 99 method. Long-distance production for raw materials was considered for all cases and glass-ceramic cooktop was considered for the homemade scenario.

Fig. 4 Single score employing the Eco-indicator 99 method of the homemade dish, using electric glass-ceramic cooktop or gas cooker

Fig. 5 Carbon footprint calculated as Global Warming Potential (CML 2 baseline 2000 V2.04/World 1990 method)

Table Captions

Table 1. Summary of the inventory data per functional unit (1 kg of product ready to be consumed)

Table 2. Data bases used in LCIA

Table 3. Relative contribution of the main subsystems to the most important impact categories using the Eco-indicator 99 method. Scenarios: Factory, Catering, Restaurant, Homemade; Impact categories: Land Use, Fossil Fuels, Respiratory Inorganics, Minerals, Carcinogens, Acidification/Eutrophication, Climate Change.

Fig. 1

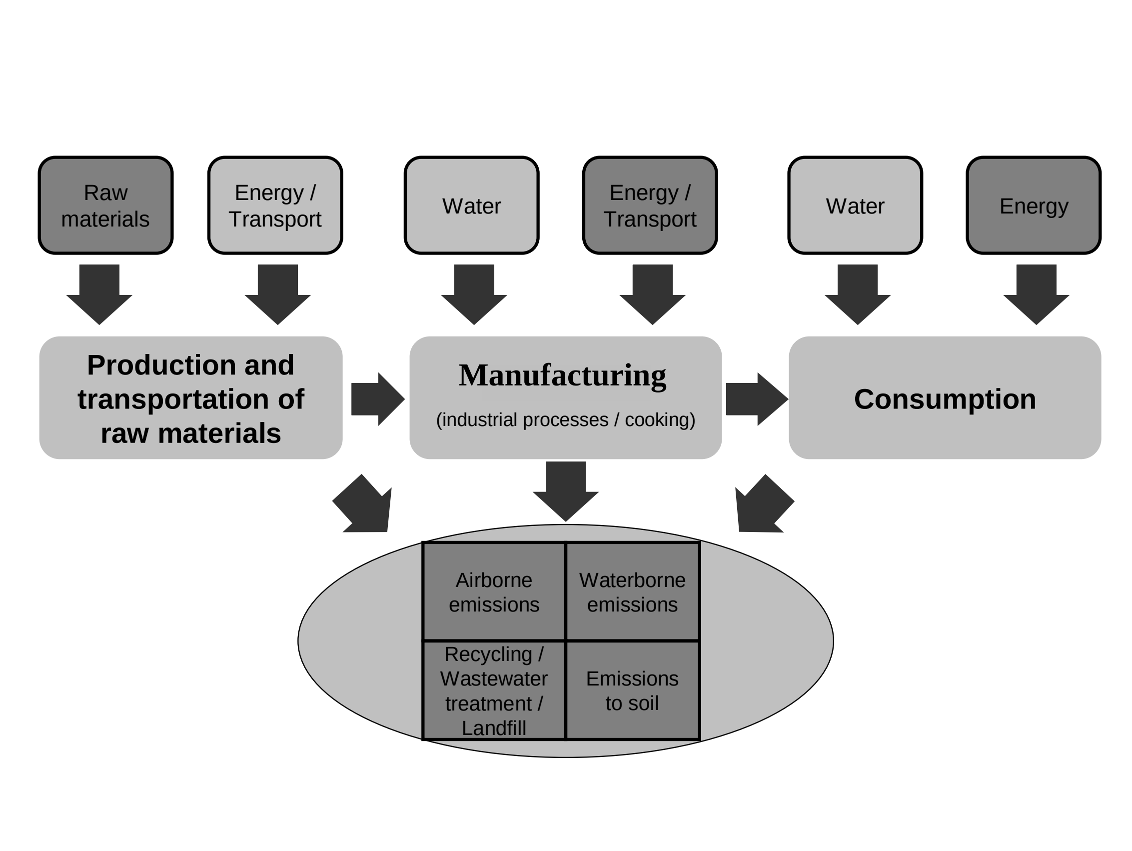
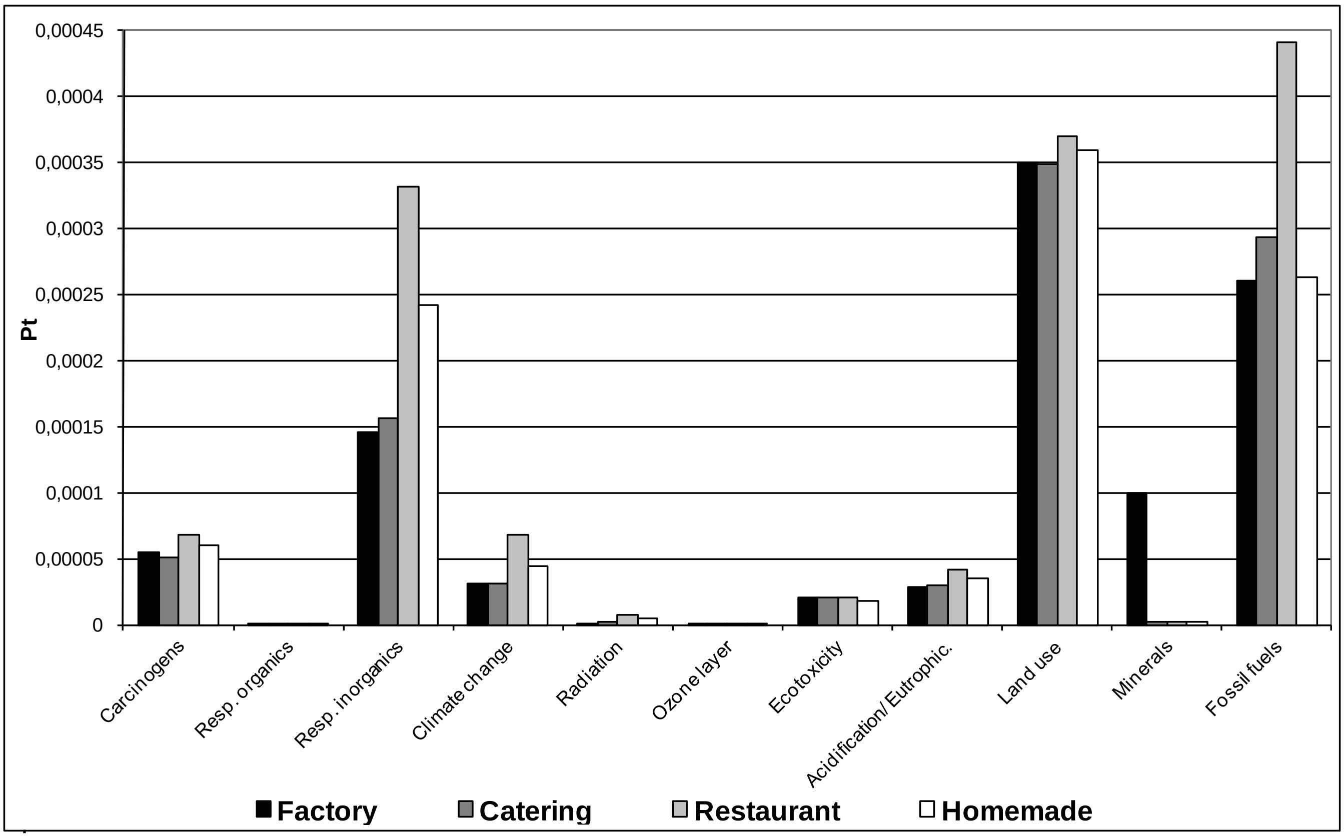

Raw materials
Energy / Transport
Water
Energy / Transport
Water
Energy
Production and transportation of raw materials
Manufacturing
(industrial processes / cooking)
Consumption
Airborne emissions
Waterborne emissions
Recycling / Wastewater treatment / Landfill
Emissions to soil

Fig. 2



0,00045
0,0004
0,00035
0,0003
0,00025
0,0002
0,00015
0,0001
0,00005
0
Pt
Carcinogens
Resp. organics
Resp. inorganics
Climate change
Radiation
Ozone layer
Ecotoxicity
Acidification/ Eutrophic.
Land use
Minerals
Fossil fuels
Factory
Catering
Restaurant
Homemade

Fig. 3

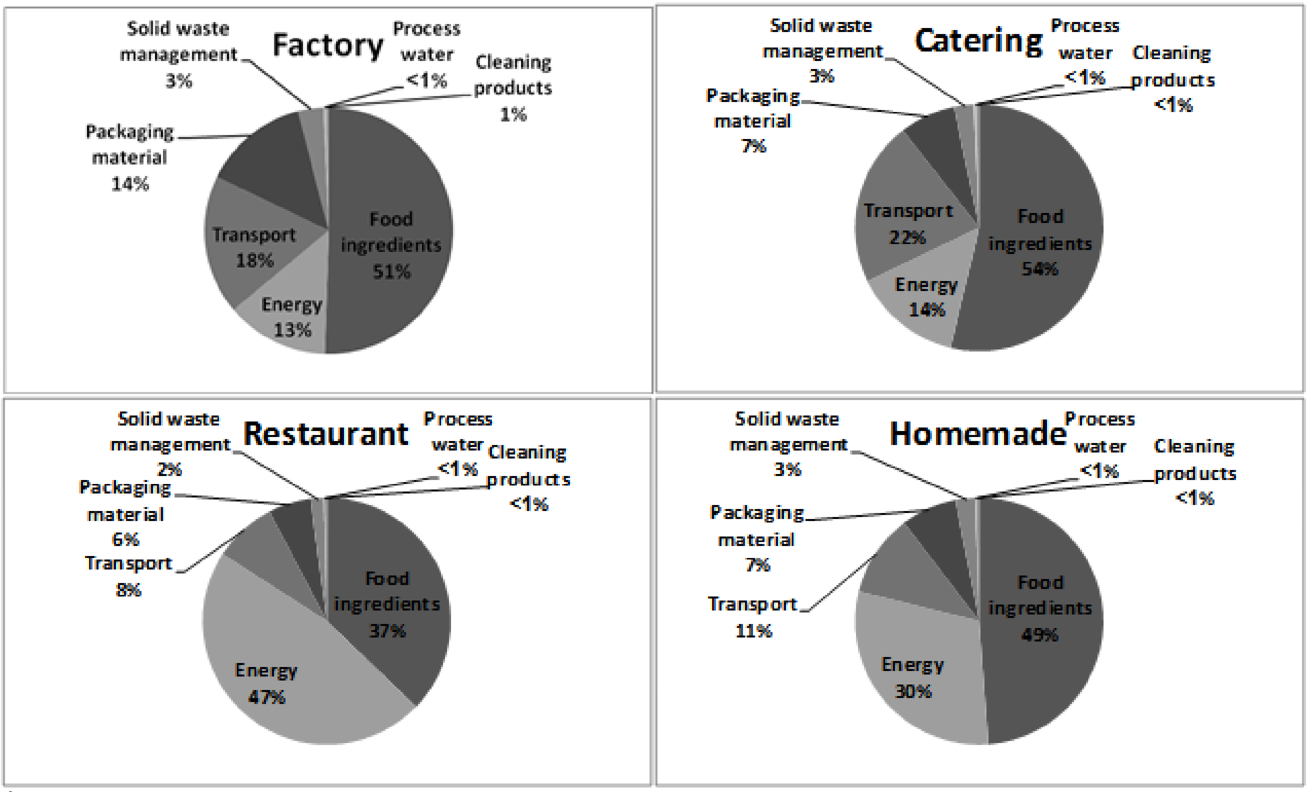

Factory
Solid waste management 3%
Process water <1%
Cleaning products 1%
Packaging material 14%
Transport 18%
Food ingredients 51%
Energy 13%
Catering
Solid waste management 3%
Process water <1%
Cleaning products <1%
Packaging material 7%
Transport 22%
Food ingredients 54%
Energy 14%
Restaurant
Solid waste management 2%
Process water <1%
Cleaning products <1%
Packaging material 6%
Transport 8%
Food ingredients 37%
Energy 47%
Homemade
Solid waste management 3%
Process water <1%
Cleaning products <1%
Packaging material 7%
Transport 11%
Food ingredients 49%
Energy 30%

Fig. 4

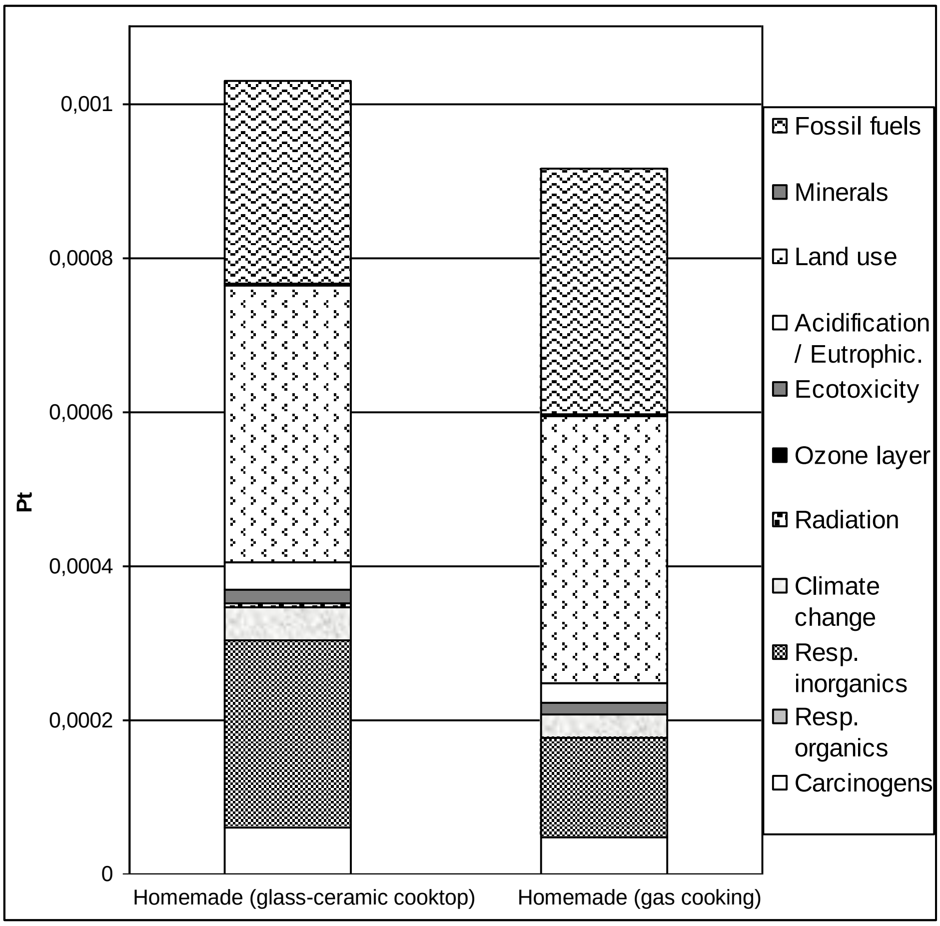

0,001
0,0008
0,0006
0,0004
0,0002
0
Pt
Homemade (glass-ceramic cooktop)
Homemade (gas cooking)
Fossil fuels
Minerals
Land use
Acidification / Eutrophic.
Ecotoxicity
Ozone layer
Radiation
Climate change
Resp. inorganics
Resp. organics
Carcinogens

Fig. 5

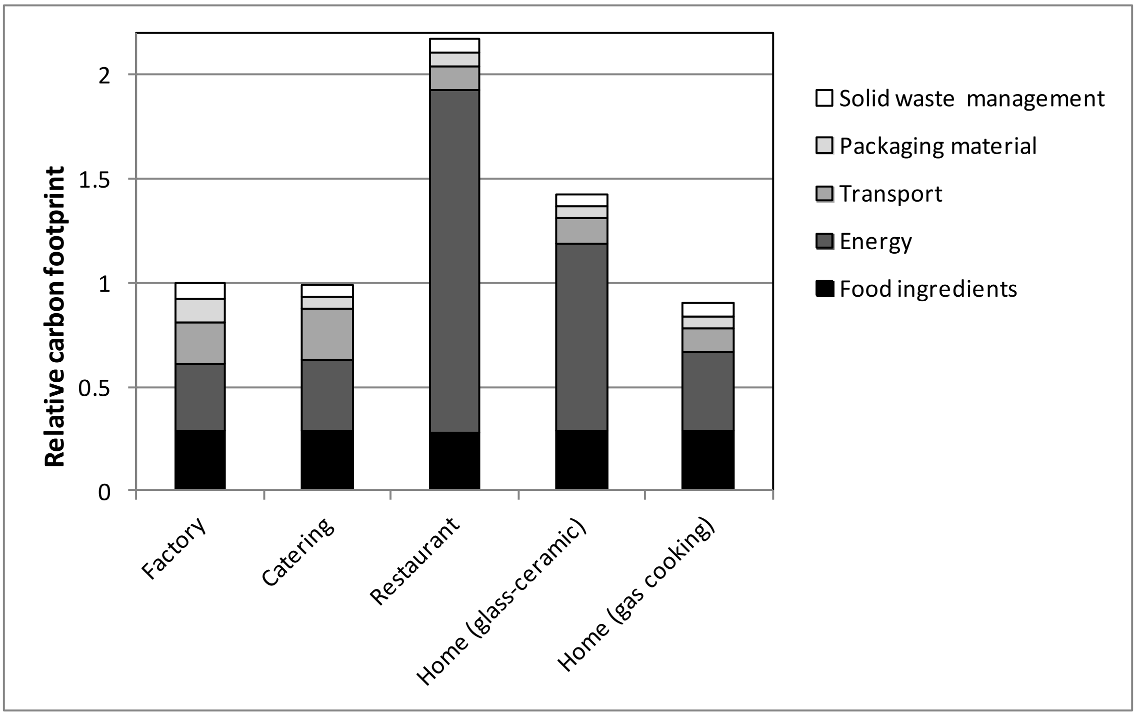

Relative carbon footprint
0
0.5
1
1.5
2
Factory
Catering
Restaurant
Home (glass-ceramic)
Home (gas cooking)
Solid waste management
Packaging material
Transport
Energy
Food ingredients

Table 1

Subsystems		Factory		Catering		Restaurant		Homemade	
		Inputs	Outputs	Inputs	Outputs	Inputs	Outputs	Inputs	Outputs
Food ingredients[1]		475.6 g[a]		475.6 g[a]		475.6 g[a]		475.6 g[a]	
	[a]43% pork meat cuts, 41% pulses, 10% salt, 6% onion (water not included)								
Process water[2]	Consumed tap water	19.7 l[b]		7.9 l[c]		7.9 l[c]		10.5 l[d]	
	[b]9.2 l in the factory, 8 l dishwasher, [c]1 l beans soaking and cooking, 6 l dishwasher, [d]1.5 l beans soaking and cooking, 9 l dishwasher								
	Wastewater		16.7 l		6.5 l		6.5 l		8.5 l
Cleaning products[3]		13.3 g		10 g		10 g		10 g	
Packaging material[4]		137.7 g[e]		43.6 g[f]		40 g[g]		40 g[g]	
	[e]91% tinplate, 6% cardboard, 3% plastic [f]89% plastic 11% cardboard (tray and packaging) [g]100% plastic (ham packaging)								
Solid wastes[5]	To landfill		283.5 g[h]		204.4 g[i]		235 g[j]		235 g[j]
	[h]81% organic matter, 16% tinplate, 3% others [i]98% organic matter, 2% others [j]85% organic matter, 15% plastic								
	To recycling		90.7 g[k]		40 g[l]		13 g[m]		13 g[m]
	[k]89%, tinplate, 9% cardboard, 2% plastic [l]89% plastic,11% cardboard [m]100% plastic								
Transport[6]	By ship		1950 kgxkm		1950 kgxkm		1950 kgxkm		1950 kgxkm
	By lorry		1035 kgxkm		196 kgxkm		146 kgxkm		146kgxkm
Energy[7]	Natural gas	55 l		40 l		179.5 l			
	Electricity	1.1 kWh[n]		1 kWh[o]		6.31 kWh		3.9 kWh[p]	
	[n]0.2 kWh at industrial level 0.9 kWh at domestic level, [o]Reheating: 0.4 kWh Dishwasher: 0.6 kWh, [p]Cooking: 3.1 kWh Dishwasher: 0.8 kWh								
Finished product that is eaten[8]			800 g[q]		800 g[q]		800 g[q]		800 g[q]
	[q]20% of the foodstuff cooked turns into waste								

[1]Data supplied by the factory (considered the same for the other scales)

[2]Data supplied by the factory, the catering company, the traditional restaurant and a house cook. Water consumed for the washing up was calculated from industrial and domestic dishwasher consumption

[3]Data supplied by the factory and calculated from dishwasher consumptions

[4]Data supplied by the factory, the catering company and the traditional restaurant (supposed the same for homemade scale)

[5] The amount and composition of the solid wastes produced during the elaboration of the ready meal were supplied by the factory (supposed the same for catering scale) and the restaurant (supposed the same for homemade scale). For factory and catering scales, the packaging wastes were also considered. Cooked food remains were considered to be a fifth of the total for all cases (Ventour 2008). The amount of wastes that are landfilled and recycled was calculated considering industrial information and the average recycling percentages in Spain (Ecoembes report 2007)

[6]The transport of raw materials was calculated from information supplied by the factory and the same was supposed for the other scales. The transport of the final product was calculated from information supplied by the factory and the catering company

[7]Data supplied by the factory, the catering company and the traditional restaurant and calculated from the cooktop and dishwasher wattages for home consumption.

[8]Calculated by subtracting the foodstuff that turns into waste to the functional unit (supposed to be a fifth of the total; Ventour 2008).

Table 2

Food ingredients	
Pulses and salt	Ecoinvent v2
Meat products and onion	LCA Food DK
Process water	
Tap water	LCA Food DK
Wastewater treatment	Ecoinvent v2
Cleaning products	
Bleach and industrial detergents	Ecoinvent v2
Packaging material	
Cardboard and plastic	Ecoinvent v2
Tin plate, cans	BUWAL250
Solid waste management	
Recycling and landfill	Ecoinvent v2
Transport	
Road transport	LCA Food DK
Ship transport	IDEMAT 2001
Energy	
Natural gas	Ecoinvent v2
Electricity	ETH-ESU 96

Table 3

		SUBSYSTEMS																			
		Food ingredients (meat products)				**Energy (electricity)**				**Transport**				**Packaging material**				**Solid waste management**			
SCENARIOS:		Fac	Cat	Res	Hom	Fac	Cat	Res	Hom	Fac	Cat	Res	Hom	Fac	Cat	Res	Hom	Fac	Cat	Res	Hom
IMPACT CATEGORIES	Land Use	97% (62%)	97% (62%)	92% (58%)	94% (60%)	<1%	<1%	7% (7%)	5% (5%)	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%
	Fossil Fuels	23% (18%)	20% (16%)	13% (11%)	23% (17%)	26% (9%)	20% (9%)	60% (32%)	33% (33%)	40%	42%	14%	23%	10%	17%	12%	21%	<1%	<1%	<1%	<1%
	Respirat. Inorganics	31% (26%)	29% (25%)	14% (12%)	19% (16%)	38% (28%)	30% (30%)	70% (70%)	59% (59%)	36%	32%	11%	16%	4%	9%	5%	6%	<1%	<1%	<1%	<1%
	Minerals	<1%	37% (3%)	48% (3%)	57% (4%)	<1%	6% (5%)	36% (32%)	24% (24%)	<1%	43%	4%	5%	98%	3%	3%	3%	<1%	<1%	<1%	<1%
	Carcinog.	58% (<1%)	63% (<1%)	46% (<1%)	52% (<1%)	8% (8%)	10% (10%)	36% (36%)	25% (25%)	<1%	3%	<1%	<1%	<1%	<1%	<1%	<1%	30%	23%	17%	21%
	Acidif. Etrophic.	61% (58%)	58% (55%)	42% (41%)	50% (48%)	10% (10%)	11% (10%)	39% (38%)	28% (28%)	27%	24%	14%	16%	<1%	6%	5%	6%	<1%	<1%	<1%	<1%
	Climate Change	29% (29%)	29% (29%)	13% (13%)	20% (20%)	32% (25%)	34% (30%)	76% (67%)	63% (63%)	20%	25%	5%	8%	11%	5%	3%	4%	8%	6%	3%	4%