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Industrial Processing *versus* Home Cooking: An Environmental Comparison between Three Ways to Prepare a Meal

Today there is a strong trend in Sweden for industrially processed meals to replace homemade meals. In the public debate this is often claimed to increase the environmental impact from foods. In the study presented in this article, we used life-cycle assessment to quantify the environmental impact of three meals: homemade, semiprepared, and ready-to-eat. The differences in environmental impact between the meals were small; the ready-to-eat meal used the most energy, whereas the homemade meal had higher emissions causing eutrophication and global warming. The dominating contributor to the environmental impact was agriculture, accounting for 30% of the impact related to energy and 95% of that related to eutrophication. Industry, packaging, and consumer home transport and food preparation also contributed significantly. Important factors were raw material use, energy efficiency in industry and households, packaging, and residue treatment. To decrease the overall environmental impact of food consumption, improvements in agriculture are very important, together with raw-material use within industry and households.

INTRODUCTION

Food accounts for a significant share of the total environmental impact in society. The environmental impacts arise in all parts of the life cycle of food products: agriculture, industry, retail, transport, and last but not least, the consumer phase. The food system also uses a large proportion of all packaging material produced. The total environmental impact from the food system per capita differs between countries and regions as a result of the types of food eaten and the efficiency, in a broad sense, of the farm-to-fork system. Of the total energy use in society in Sweden, 20% can be attributed to the food supply system; the largest consumers being agriculture, the food industry, and households, followed by transport, retail, and packaging (1). For eutrophication, agriculture is the largest source. Approximately 50% of all eutrophying emissions in Sweden come from agriculture, whereas the remainder originate mainly from sewage treatment and transport (including transport of foods) (2–4). The contribution of the food system to total emissions of greenhouse gases is around 28% (5). This figure is based on the food system use of 20% of total energy, which corresponds to 15% of total emissions, while agricultural emissions make up the rest. In agriculture, organic pesticides are also used rather intensively.

In many parts of the western world today, there is an overconsumption of fat and protein, which involves an extra environmental impact compared with a more balanced diet. However, despite potential changes in diet, it remains a fact that supplying people with food will continue to constitute a significant environmental burden in the future, and with an increasing population, the impact will increase accordingly. Hence, it is of vital importance that the systems for producing, processing, and distributing food be as efficient and environmentally sound as possible.

Today's trend, in the industrialized world, is for an increasing proportion of the food consumed to be prepared industrially. Ready-to-eat meals and semiprepared products are the markets within the food sector with the strongest growth, implying that food preparation is increasingly being carried out within industry instead of in households. In Sweden, sales of frozen, ready-to-eat meals increased by 23% between 2000 and 2002, and sales of prepared potato products increased by 75% between 1990 and 2002, whereas sales of raw potatoes decreased by 30% during the same period (6). This is often considered to increase the environmental impact and resource consumption; a lot of energy is used within industry, and transport of chilled or frozen foods is also energy-demanding. Industrially processed food also requires more packaging. However, energy use or wastage does not necessarily increase through industrial processing. It takes less energy to heat food in large batches than in small, and within industry it is possible to use heat recovery. Because most foods need heating, it is mainly a matter of where this should be done. The increased use of packaging and often longer transport still favor home cooking, and the fact that most industrially processed foods are reheated before consumption must also be taken into account.

There are a large number of articles that describe environmental assessments of individual foods using life-cycle assessment (LCA) (7–12), but studies describing whole meals are limited. Kramer (13) presented a study on food consumption in the Netherlands and identified options for decreased emissions of greenhouse gases and energy use employing a methodology based on national statistics on energy use and emissions from different sectors.

In general, it seems that the question of the environmental superiority of homemade or industrially prepared food concerns whether the more energy-efficient industrial preparation balances the increased inputs required in transportation, packaging, and reheating. The question of raw-material use is ambiguous because for some products, home preparation is more efficient, and for others, industrial processing has the advantage. This is probably important because agriculture causes a large share of the total life-cycle impact of food products; hence a higher use of raw materials gives a lower environmental impact per unit consumed.

Our main aim with this study was to discuss how the present trend toward more industrially prepared foods affects environmental impact and energy use. A second aim was to clarify the parts and activities in the supply chain for a whole meal that cause the different types of environmental impact. Our objective was to present environmental profiles for three ways of getting a meal on the table, with varying degree of industrial processing.

We are well aware that different means of cooking provide other functions than mere nutrient and energy supply (14), but in practice, many people consider a ready-to-eat meal to be interchangeable with a corresponding homemade meal. We chose to work with LCA methodology because it offers a comprehensive and well-documented framework for issues of this kind.

METHOD

System Boundaries

When performing systems studies of the kind presented here, it is of vital importance to define the systems boundaries. These boundaries are a result of the questions posed and, hence, the conclusions that can be drawn. The system included in the analysis presented here is depicted in Figure 1. The differences caused by the three ways of preparing the meals are within the core system, whereas components of the background systems are included in the quantification but are similar for all meals. The reason for including these background systems is to get the total environmental impact for each meal. The three ways of preparing the meal and the systems needed to provide the meal are referred to as "scenarios."

For the background systems, factors such as energy production, emissions, and resource use to provide the input needed in the core system were calculated. Similar calculations were performed for the production of inputs to agriculture, for example, mineral fertilizers. These system boundaries follow the methodology and recommendations for LCA (15).

Sewage treatment of food waste after consumption (i.e. urine and feces) was not included; the sewage treatment in Figure 1 represents treatment of effluents from industry. In Sonesson, Jönsson, and Mattsson (16), this important part of the life cycle of foods is discussed, and according to their study, emissions from sewage treatment of these flows can be omitted if the products analyzed have the same content of nutrients and fiber, which was the case in the present study.

Modeling

To quantify variants of the same basic systems, or scenarios, it is convenient to use mathematical simulation models. Using simulation models allows a large number of calculations to be performed, which facilitates an iterative working process, whereby data gathering can be guided by information from the simulations about the most important parts of the systems. By using models, it is also easy to make sensitivity analyses on critical assumptions made.

We used the simulation model SAFT, which was first developed and used in a project about dairy products (17). The model was complemented with models for other industrial processes and the parts dealing with household energy use were improved. SAFT is basically a material flow model, i.e. a certain amount of food raw material enters the model at one end, the product flows through the system, and all use of energy and emissions that occur as a result of the flow are calculated. Finally, consumed products leave the system at the other end. Throughout the SAFT model, vectors are used to describe all flows of material and energy between submodels. All emissions are also described by the same vector; emissions are calculated as single substances. In this study, the inflow was calculated as the required amount of raw material needed to get a certain amount of food on the table, taking into account all losses between farm and table. Waste management and residue treatment result in recovery of energy and materials but give rise to emissions. This was treated in such a way that if energy was gained by incinerating packaging, it was presented as negative energy use for waste management. The emissions resulting from the incineration were calculated and included. At the same time, the emissions that would have occurred from combustion of oil to produce the same amount of heat as was derived from incinerating the packaging were presented as negative emissions. This approach is often used in LCA and is called "avoided burden." The model and the parameters used are described in detail by Sonesson and Davis (18).

Data Gathering

Generally, the data used reflected the present food chain in Sweden. As input data to the model, a number of sources were used, but results from several LCAs on Swedish food products were the most common source. Other sources included other studies of food systems, such as energy analyses. Engineering data and information from food-producing companies were used for modeling the industries. Finally, experiments were carried out when no data were found in literature, e.g. regarding food preparation and wastage in households. All data used are presented, along with references, by Sonesson and Davis (18). Domestic transport by consumers between retailer and household was modeled based on a survey of Swedish households (19).

Scenarios Studied

Three scenarios were studied, all of them supplying one common function: to deliver one meal on the table in a private Swedish household. All three meals consisted of the same amount of all ingredients, so the mass flow out of the system (i.e. into the mouth of the consumer) was equal in all three scenarios. Because the different systems showed different raw material use, the amount of input from agriculture differed and, hence, the environmental impact from agriculture also differed. The meal consisted of meatballs with potatoes, bread, carrots, and milk. This meal was chosen because it is a common meal in Sweden and because it can be purchased both as a frozen, ready-to-eat meal and as semiprepared components (mashed potato powder and chilled fried meatballs). To simplify the calculations and because of data gaps, some components of the meal were omitted, namely eggs, onions, frying fat, and dried breadcrumbs (for the meatballs). Because the flows were rather similar in all scenarios, the comparison between scenarios was not affected, and the total impact calculated was only slightly lower for all scenarios.

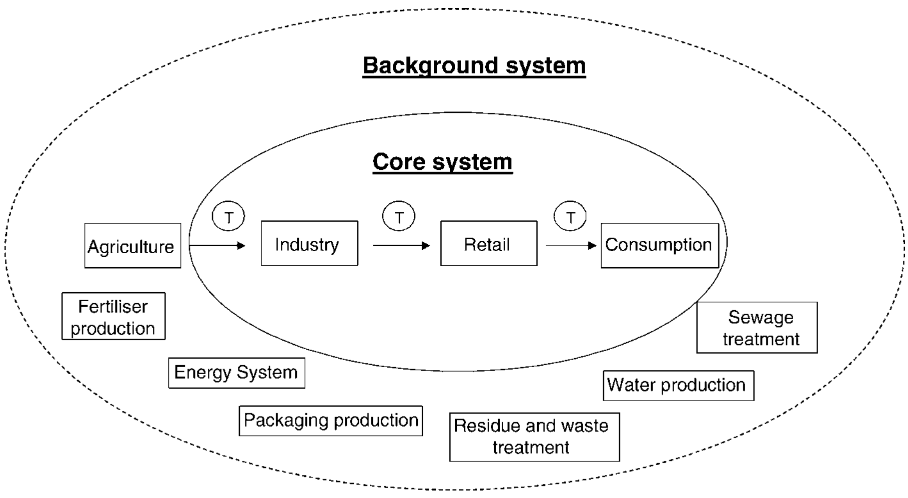

Figure 1. Systems boundaries used in the study. The "T" represents transport.

Table 1. Principal description of the three meal-preparation scenarios.

Systems part/scenario	Homemade	Semiprepared	Ready-to-eat
Agriculture	Today's conventional Swedish agriculture is assumed to produce the raw materials for the meal	Same as Homemade	Same as Homemade
Transport to primary industry	Heavy trucks with trailers	Same as Homemade	Same as Homemade
Primary industry	The milk is processed in a large, highly automated dairy. The wheat is milled in a modern mill. The carrots and potatoes are sorted, cleaned, and packed at respective packer. The pigs and cattle are slaughtered in a large-scale abattoir, and the carcasses are divided into joints on site for further delivery to retailers, where the meat is minced.	Same as Homemade; potatoes are processed in one industry only, which is described below	Same as Homemade; potatoes are processed in one industry only, which is described below
Transport to secondary industry	Not relevant	All transport to the secondary industry is done by truck and trailer	Same as Semiprepared
Secondary industry	Not relevant	This industry prepares meatballs and packs them in plastic as a chilled product; mashed potato powder is produced and packed in aluminum bags and a cardboard box; bread is baked in an industrial bakery	These industries prepare meatballs, boiled potato, and blanched carrots and pack them frozen in two-portions boxes (plastic and cardboard); milk and bread same as Semiprepared
Transport to retailer	Depending on product, the transport is either performed with heavy trucks or trucks and trailer	Same as Homemade for carrots and milk; bread is distributed in its own system; meatballs are transported in chilled trucks, and the distances are generally longer	Freeze-transport of the meal; bread is the same as Semiprepared; milk is the same as Homemade
Retailer	Today's shopping habits and retail structure; the products are stored and displayed as today	Same as Homemade	Same as Homemade
Home transport	This activity reflects today's shopping and travel pattern, based on a survey presented in Sonesson and Davis (18)	Same as Homemade	Same as Homemade
Household	The meatballs are fried in a pan, the potatoes are boiled, and bread is baked in an electric oven	Potato powder cooked on electric stove top, meatballs heated in frying pan.	No baking of bread or boiling of potato, meal heated in microwave oven.

The differences between the three scenarios regarding the meal were:

- Homemade meal: Potatoes are boiled in water, the meatballs are prepared from minced meat and fried in a frying pan, and bread is baked at home. All food is prepared on a stove top and in an oven. Carrots are peeled and eaten raw. Milk is served with the meal.
- Semiprepared meal: Chilled meatballs are heated in a frying pan, and mashed potato powder is prepared on a stove top and in an oven. Bread is produced in a large industrial bakery. Carrots are peeled and eaten raw. Milk is served with the meal.
- Ready-to-eat meal: A frozen, ready-to-eat meal consisting of meatballs, boiled potato, and carrots is heated in a microwave oven. Bread is produced in a large industrial bakery. Milk is served with the meal.

In all scenarios it was assumed that the meal was consumed on the day of purchase, therefore, no energy for home storage was required.

Based on the composition of the meals, the systems delivering these meals were described. Table 1 lists the principal differences in all systems components between the three scenarios.

One important question when performing systems studies of the kind presented here is the matter of how the energy used within the system is produced. Electricity in particular can be produced by means that differ greatly in their environmental impact; e.g. hydroelectric power gives practically no emissions, whereas coal-fired power plants emit large amounts of carbon dioxide. Because this study aimed to show the current environmental impact from a meal served in Sweden, we chose to assume that all electricity was produced as the average Swedish electricity, comprising about 45% hydroelectric power, 45% nuclear power, and the remainder being generated from oil, coal, and gas. The exception was the production of plastic packaging, which was made outside Sweden, and the electricity used for its production was assumed to be average EU-electricity; more coal- and oil-fired power plants and much less hydroelectric power. Overall, this meant that processes using electrical energy showed low emissions (except manufacturing of plastic packaging) compared with processes using the same amount of heat produced by fossil fuel. The waste management in all scenarios reflected the current situation in Sweden, but the proportion put to landfill was lower because of forthcoming legislation. Around 60% of plastic and cardboard was assumed to be incinerated and the remainder recycled; 16% of corrugated cardboard was incinerated and the rest recycled. The solid organic waste was assumed to be 90% incinerated and the rest dumped in landfills.

Environmental Effects Included

The results from the simulation consisted of a number of parameters, both emissions of different substances and use of resources, e.g. fuel. Table 2 shows the parameters relevant for the present study.

Table 2. The environmental parameters calculated by the simulation model used in this study.

Air emissions	Carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), volatile organic substances (VOC), ammonia (NH_3), nitrous oxides (NO_X), sulfur oxides (SO_X), dinitrogen oxide (N_2O), hydrochloric acid (HCl)
Water emissions	Organic matter (COD/BOD)*, Ammonium (NH_4^+), Nitrate (NO_3^-), Phosphorus (P)
Resource use	Total net energy use, use of primary energy carriers

* COD/BOD = chemical and biochemical oxygen demand.

The emissions calculated were then transformed into environmental effect categories according to LCA methodology (20). This methodology basically consists of grouping substances affecting the same environmental effect and adding them together in one unit using different weighting factors, which reflect how severely the substance affects that particular environmental effect. The effect categories included were: eutrophication, acidification, global-warming potential, and formation of photooxidants caused by organic substances. NO_X affects several environmental parameters, e.g. human health and the formation of photooxidants; therefore, it is presented as the amount of the substance emitted. However, NO_X also contributes to eutrophication and acidification and is included in these effect categories as well, according to LCA methodology. Information on weighting factors is found in Sonesson and Davis (18).

The resource use presented here only concerns energy, although other resources used can, of course, also be relevant. The secondary energy use for the system is presented as megajoule (MJ) energy use for each system component, e.g. dairy, retailer, or households. These figures represent the energy "on the electricity bill," i.e. MJ electricity and fuels delivered to the system. This means that the energy used in the energy system for extraction, refining, and transportation is not included. To reflect the use of energy resources in terms of amount of fossil fuels and uranium, their use is presented as primary energy carriers, i.e. gross amount of energy resource extracted. These two results complement each other; the secondary energy use is a good basis for improvement of the core systems, and the primary energy carriers give a picture of the total resource use for the scenarios.

Compilation and Presentation of Results

The results presented are product-orientated; this means that the environmental impact presented is a result of the resources needed for the meal in question. Accordingly, a decreased need of food raw material will result in a decreased environmental impact, regardless of what the resulting farm land made available is used for (instead of producing raw material for the meal in question). This approach is logical and unobjectionable for other resources such as fuels; if less diesel fuel is needed, less crude oil will be extracted and refined and the environmental impact will be avoided. However, farm land is not a resource that can be switched off; in reality, this surplus land can either be used for producing nonfood products, thus replacing some other material, or it can be set-aside land, thus continuing to produce emissions such as nitrate leaching and dinitrogen oxide. To enable such systems effects to be taken into account, an analysis of probable outcomes of a decreased need for farm land must be performed. For simplicity, we assumed that the farm land not used for producing raw material for the system studied was used for other productive purposes, and the environmental impact was borne by the products produced, i.e. surplus farm land did not affect the environmental impact of the system studied.

Table 3. Raw material use in the three meal-preparation scenarios (percentage of the material leaving farm that ends up in the meal).

Product	Homemade (%)	Semiprepared (%)	Ready-to-eat (%)
Milk	81	81	81
Pig meat	45	46	47
Cattle meat	35	36	37
Carrot	51	51	53
Wheat	50	49	49
Potato	61	88	78

The results presented below are aggregated results from the SAFT model. The more detailed results from the model can be used to explain the aggregated results, e.g. which substances from a certain process cause the environmental impact. A complete description of the results are presented by Sonesson and Davis (18).

RESULTS

Because raw material use proved to be an important factor for some of the results, it is presented first in this section (Table 3). As can be seen in Table 3, the differences between the scenarios were small for most products; the industrial scenarios used all raw materials slightly more efficiently except for wheat, where the homemade method was more efficient. However, for potatoes there were significant differences. Peeling and cooking potatoes at home apparently produced much more waste than industrial processing, and the mashed potato industry seemed to use much more of the raw material than the industrial boiling in ready-to-eat methods.

In terms of the secondary energy use, there were no large differences between the three scenarios (Fig. 2). The homemade and semiprepared meals had approximately the same energy use, whereas the ready-to-eat meal showed a slightly higher energy use. Compared with homemade meals, semiprepared meals used more energy within the industry, but this was roughly balanced out by lower use of domestic energy (i.e. cooking at home).

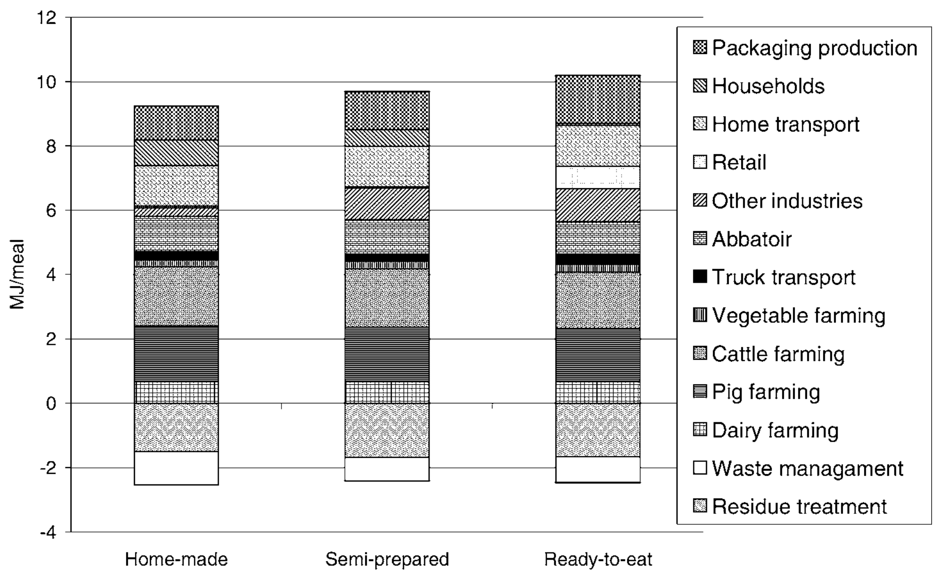

Figure 2. Secondary energy use for the three meal-preparation scenarios.

Truck transport was about the same for semiprepared and homemade methods; the fact that the mashed potato powder required less transport balanced out the increased transport of meatballs. For the ready-to-eat scenario, very little energy was used at home because a microwave oven was used to heat the meal. However, the longer storage time at the retailer consumed electricity, as did the packaging (the ready-to-eat meal used the most packaging of all three meals). The higher, negative energy use (i.e. energy gained, as explained in the Methods section) from waste management in homemade and semiprepared scenarios was explained by the fact that the packaging was recycled to a higher extent because it was easier to recycle. The residue treatment was totally dominated by incineration of meat and bone meal from the abattoir waste, the largest amount and also the most energy-rich waste came from slaughter of animals.

The use of primary energy carriers is shown in Figure 3. The comparison between scenarios showed the same outcome as that for secondary energy use (Fig. 2). This is a result of the assumption that the proportion of different energy forms was rather similar in all scenarios and hence the inclusion of the energy system's efficiency did not alter the picture. The most important primary energy carriers were fossil oil and uranium. Fossil oil was used for producing mineral fertilizers, vehicle fuels, and plastic packaging. Biofuel was mainly used for packaging production.

In general, the most important environmental impact from the food systems is eutrophication, and the food system accounts for the absolutely largest share of total eutrophication in society, as discussed in the Introduction. Figure 4 shows the results for eutrophication for the three meals studied here. In secondary energy (Fig. 2), there were no great differences between the meals but their order changed because the two scenarios with more industrialized processing showed slightly lower eutrophying emissions. This was the result of higher raw material use (Table 3) of pig and cattle meat and potatoes. Because agriculture is responsible for such a large proportion of the total environmental impact, even small changes in raw material use make a difference. It can also be noted that for this important environmental effect category, agriculture's share is even larger than for most other effect categories.

The emission of substances causing potential global warming for the three scenarios are illustrated in Figure 5. The differences that can be observed are mainly explained by the higher use of pig and cattle meat but especially potatoes in semiprepared and ready-to-eat scenarios. These two scenarios also had a slightly higher figure for avoided emissions. Those were emissions

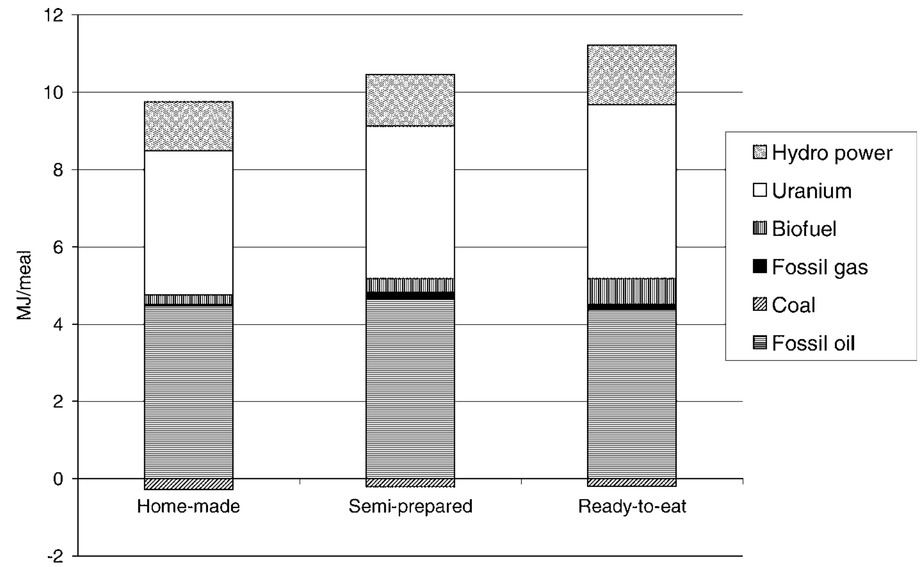

Figure 3. Use of primary energy carriers for the three meal-preparation scenarios.

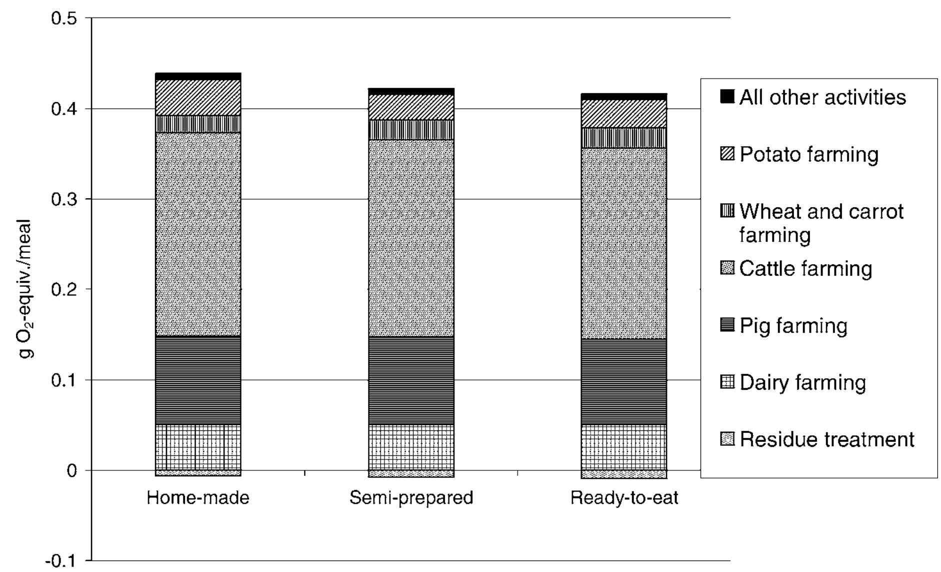

Figure 4. The potential eutrophication (in the worst case, both nitrogen and phosphorous are contributed) for the three meal-preparation scenarios.

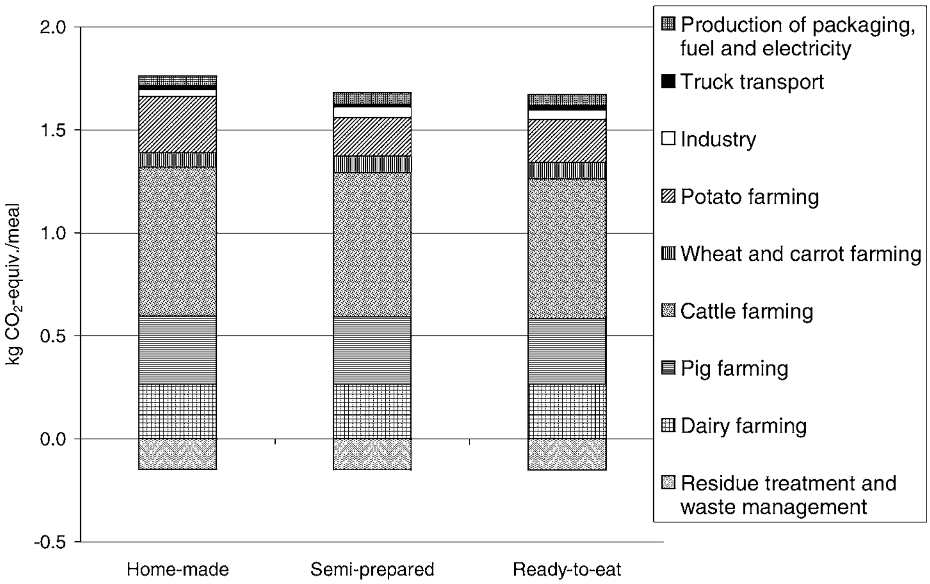

Figure 5. Emissions of potential global warming gases from the three meal-preparation scenarios.

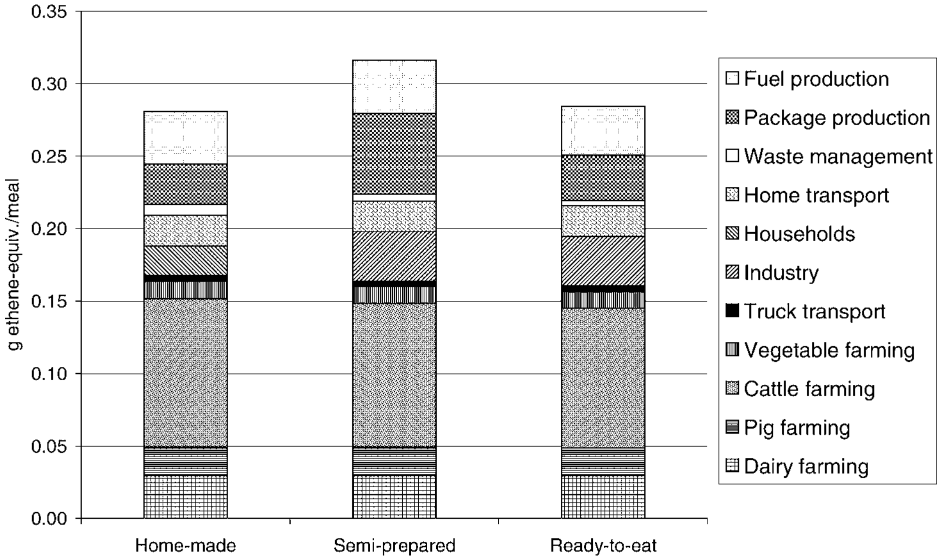

Figure 6. Emissions of substances that cause the formation of photochemical substances.

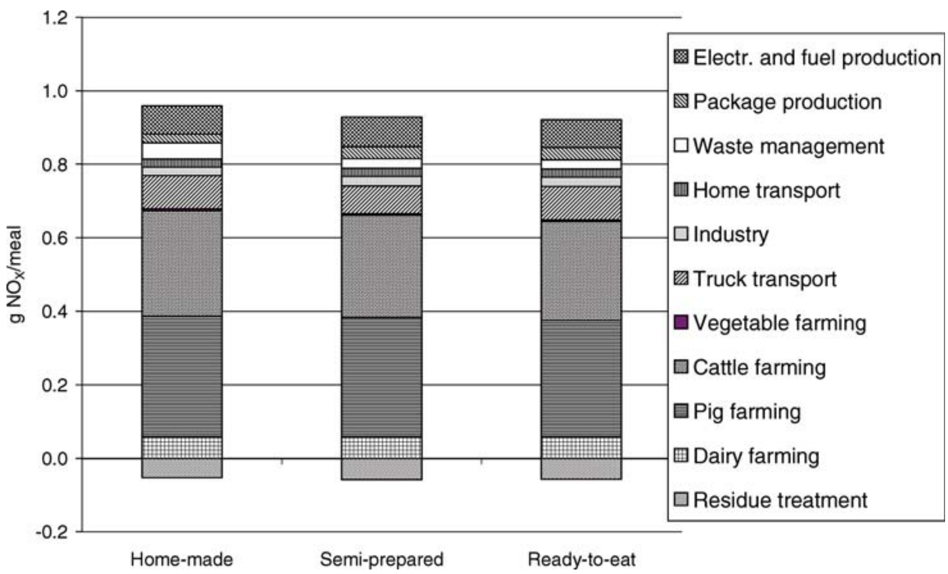

Figure 7. Emissions of NO_X from the three meal-preparation scenarios.

avoided because of incineration of meat and bone meal that replaced oil and hence replaced a fossil fuel with a biofuel. The difference was the result of different waste management; more cardboard was used in the industrialized scenarios and then assumed to be partly incinerated thereby replacing oil with biofuel.

The results for potential acidifying substances were very similar to those for global warming (Fig. 5), and the explanations are largely the same. The only difference was that the share from agriculture was even more dominant.

Emission of substances causing the formation of photochemical oxidants (ground-level ozone) exhibited more differences between scenarios than other effect categories (Fig. 6). The agricultural share of the emissions was also lower, which made the differences in raw material use less pronounced. The biggest difference arose in packaging production and waste management. The packing used in semiprepared meals was made of more plastic than in the other two scenarios, and plastic manufacturing emits more volatile organic substances. The difference in waste management was because in the homemade scenario, a relatively large amount of potato peel was dumped in a landfill, thus causing emissions of methane that affect the formation of photochemical oxidants. The emissions from industry were mostly ethanol from the rising of bread, as were the emissions from households.

Emissions of NO_X both lead to formation of photochemical oxidants and affect human health and are mainly caused by combustion (Fig. 7). The increased transport in ready-to-eat meals was obvious, but the total results showed that homemade meals emitted the most NO_X, although the differences were small. The emissions of NO_X from waste management were higher in the homemade scenario because a larger share of the waste arose in the household and was partly dumped in landfills where methane is formed, of which 50% was burned. Because less meat raw material was used in the two industrialized scenarios, the agricultural emissions of NO_X, mainly comprising emissions from production of mineral fertilizer, were lower.

DISCUSSION

Discussion of the Results

Our main aim was to analyze whether the increased consumption of industrially processed food affects the environmental impact from the food system. The results showed that there were no great differences in environmental impact arising from this factor in terms of the environmental parameters studied. This is important, because the common perception is that industrially prepared foods are worse for the environment than those that are homemade. Of course our results only reflect the present situation in Sweden, but the logic behind the results is general. In de Witte (21, cit. 13), the results for homemade versus ready-to-eat meals are presented, and the ready-to-eat meals use slightly more energy. Even if the variations in the systems studied are large and the environmental impact also varies greatly, our study shows quantified outcomes. This makes it possible to identify the improvement potential, i.e. where improvements are most efficient in a life-cycle perspective.

The results presented clearly show the importance of agriculture for the total life-cycle environmental impact of food products. This has also been reported in several research studies (e.g. 8, 10), as well as other LCA studies (22). This clear result can be interpreted in several ways; obviously, the most efficient way of decreasing the total environmental impact from food is to make agriculture more efficient. However, it also highlights the fact that the raw material use in the rest of the food chain (industry, retail, household) is important. The raw material carries a heavy environmental "rucksack," and every gram lost has caused an environmental impact that must be borne by the remaining food, making each kg of food consumed more environmentally expensive.

The losses in the systems studied were highest for the meat products and were, to a large extent, caused by the physiology of the animals. This can be continuously improved by animal breeding because an important breeding goal is to increase the percentage of meat in the carcass. However, if a larger proportion of the animal was used for some purpose, the total environmental load for rearing the animal would be divided by a larger mass hence making each kg of meat affect the environment less. For example, in the present study animal by-products were used as fuel, which decreased the environmental impact of the system. However, there are probably more efficient uses of these by-products. The same reasoning applies to the other products, and the best breeding goal for carrots and potatoes could perhaps be a tuber that could be peeled with low losses, i.e. with large volume per unit, spherical shape, with a thin and even peel.

The above discussion builds on the product-orientated approach applied throughout this article, which can be debated. If fewer agricultural products are used, the excess farmland is probably set aside today, thus continuing to cause an environmental impact. Set-aside land has a high nitrogen content and can cause nitrate leaching, even if not farmed. Despite this, we argue that to achieve a more sustainable food production system, it is crucial to increase the overall efficiency in the system. In the long term, considering the relative acute problem with global warming caused by combustion of fossil fuels, freed arable land should certainly be used as a source of bio-energy.

There were several assumptions made in this study, regarding e.g. the type of agriculture, the energy systems, the packaging production, and the waste and residue management, and these assumptions affected the results. If, for example, we had chosen to use average EU data for all electricity used within the system, the emissions from electricity production would have been higher. Looking at the use of electricity in the three systems, homemade and semiprepared scenarios had very similar use, whereas ready-to-eat meals used more. This means that ready-to-eat meals would show higher emissions, primarily of global warming potential, photochemical oxidants, and NO_X (which are the effect categories most affected by combustion of fossil fuels). The increases would not be dramatic, but they would certainly make the ready-to-eat scenario less favorable from an environmental point of view.

Another assumption that might be crucial is that no food was stored in the household. In reality, when people bake their own bread or make their own meatballs, it can be assumed that a larger batch is produced, and some is put into the freezer or refrigerator for later use. This would increase the energy use for the homemade meal. On the other hand, perhaps people buy more than one portion of ready-to-eat meals, and keep them in the freezer as well.

The quantification made assumed that all three meals were produced in sufficient numbers to facilitate large-scale distribution and processing. If batches of each component became too small or if transport became less efficient because of stronger demand for just-in-time delivery of foods, the results might change.

Discussion of Method

When performing analyses of large and complex systems, such as the system needed to produce a meal, several methodological issues arise. The first difficulty is that the systems studied are not fully comparable: homemade meatballs are considered by some to taste better, there could be differences in nutritional value between the meals, and so on. This must be remembered when drawing conclusions about the environmental impact of the three systems. In our study, we considered the three meals to be interchangeable because many people make daily choices between the three meals, and we think this is relevant for a study of this kind.

The systems under study, and our model representing them, are very large and complex. This brings in the problem of data uncertainty because a vast number of parameters needed to be quantified. We mostly used published data from previous LCAs and similar studies, and to complement these data, we used a wide range of sources. There is a risk that some data are less valid, but a comparison of our results with studies of single-food products did not reveal any deviations that could not be explained. We chose to use averages of the current system as input data, but for a prospective study, data representing future technologies and systems would have to be used. The use of raw material was a critical parameter for which we used first-hand data from manufacturers regarding industrial processes and carried out our own experiments on household losses.

CONCLUSIONS

The most important conclusion was that all three meals showed relatively similar environmental impacts, and the differences were too small to draw any conclusions regarding the most environmentally favorable scenario. This may come as a surprise because in the public debate, processed meals are regarded solely as a negative development. However, the results obtained are only valid for the meal studied here, and the results could be very different for other meals, both in terms of technological choices and, perhaps even more importantly, the raw materials used. Raw material use is a critical matter for food systems because the largest part of the environmental impact occurs early in the life cycle, making losses environmentally costly.

We think that the holistic approach employed by LCA methodology is important when discussing issues of more-sustainable food consumption because looking at too narrow a system may give rise to misleading conclusions. The use of simulation models is very valuable; it enables us to analyze the effects of different assumptions, which is crucial when discussing the results.

Foods, in general, have more than one function. Besides fulfilling the need for nutrients and energy, food also provides pleasure during both preparation and eating, as well as social and ethnic markers. This is complicated, and our conclusion is that this can best be taken into account by acknowledging this multifunctionality in discussions and not making absolute claims about the most preferable system. It is important to always note under what assumption of the food's function a certain conclusion is made.

In further work, it would be interesting to make prospective studies, i.e. try to find systems that are better than today's, instead of just providing a snapshot of how the system looks today. In such prospective studies, the background system—such as agriculture, energy system, and postconsumption sewage treatment—could also be changed. Increased knowledge of consumer activities is also required before conclusions can be drawn about the best method, from an environmental point of view, of delivering a meal.

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