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Environmental impact of four meals with different protein sources: Case studies in Spain and Sweden

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ABSTRACT

The production of food protein has a considerable impact on the environment. This paper investigates the potential environmental benefits of introducing more grain legumes in human nutrition. Four meals with different amounts of soybeans or peas (either used as feed for production of pork or directly consumed) were analysed using life cycle assessment methodology. The results of this analysis demonstrate that it is environmentally favourable to replace meat with peas. In particular, the addition of more legumes to human nutrition potentially aids in the reduction of global warming, eutrophication, acidification, and land use; however, in terms of energy use, a completely vegetarian pea burger meal requires the same amount of energy as other meat-containing meals. Feeding pigs with European-produced peas instead of imported soybeans, in addition to partial replacement (10%) of meat protein with pea protein, failed to reduce the environmental impact of the meal. In summary, peas can be considered 'green', but there remains a significant need for more energy-efficient processing of vegetarian products.

1. Introduction

Food is a major contributor to both local and global environmental impact and resource use. For example, Steinfeld et al. (2006) stated that 18% of global emissions of green house gasses is due to the animal husbandry sector alone, which means that the food sector as a whole contributes even more.

One of the most important components in our diet is protein, both nutritionally and from the point of view of the resources needed and the environmental impact caused when producing it. Proteins are often used as an indicator for food security, that is, if the protein supply is sufficient, then the food supply can be said to be sufficient, since the energy derived from food can be supplied by proteins and by the two other macro-components of food, fat and carbohydrates. Micronutrients (e.g., iron, magnesium, calcium, and zinc) are very important for a healthy and balanced diet. Since the meals investigated in our study were defined according to the dietary recommendations, we assume the micronutrients continued therein to be balanced.

In Europe, the primary dietary source of protein is meat. According to De Boer, Helms, and Aiking (2006), European diets include 40 kg of protein per year, of which 62% is of animal origin. Pork is the primary type of meat produced (Eurostat., 2008). Meat production in Europe highly depends on imported plant protein supplies as feed, which predominantly include soya that primarily originates from South America. Approximately 70–80% of all feed protein concentrates used in Europe are imported (Crépon, 2004). The production of soya in these South American countries causes severe environmental problems, including soil erosion and emissions from increased global transports. The increase in soya production in South America also increases pressure on the remaining rain forests in that region of the world (Fearnside, 2008).

One way of reducing the negative impact of European overseas soya dependence is to instead use grain legumes, e.g., field peas, faba beans, or lupins, grown within Europe. Growing more grain legumes has several agricultural and environmental benefits, as discussed by AEP (2006), Nemecek et al. (2008).

A relatively large number of studies have assessed the environmental impact of various food products using life cycle assessment (LCA), which is a methodology that covers the entire "cradle-to-grave" impacts of products (more on LCA in Section 3). LCA has primarily been applied to food produced in Europe, in particular western and northern Europe (e.g., Andersson, 1998; Berlin, 2002; Thomassen, van Calker, Smits, Iepema, & de Boer, 2008; Ziegler, Nilsson, Mattsson, & Walther, 2003), but the use of LCA for foods is rapidly expanding (e.g., Avraamides & Fatta, 2008; Dalgaard et al., 2007). The results from LCA studies generally indicate that vegetable products have lower impacts and resource use per kg compared to meat, with dairy products in between; however,

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differences in agricultural production, transport distances, and transport method can alter the general picture of environmental impact per kg of food for vegetable versus animal products. Moreover, a comparison between products must also encompass differences in nutritional value and preferably other functions of foods, like taste experience and possibly cultural identity.

One way of managing this complexity is to study diets or meals, thus including these factors on an aggregate level. An example of this was presented by Dutilh and Kramer (2000), who analysed the energy use in some aggregate food chains, and concluded that meat was the most energy-demanding type of food, but some vegetable products could be just as energy demanding. Kramer, Moll, Nonhebel, and Wilting (1999) analysed the emissions of global warming gases from the total food consumption in the Netherlands using a combination of LCA and environmental input–output analysis. Since the results were aggregated, no discussion or conclusions were possible on comparisons and improvements within product groups. Carlsson-Kanyama (1998) also focused on the global warming potential in her study. As opposed to Kramer et al. (1999), she analysed different meals with similar contents of protein and energy. A comparison between protein from pork and quorn was presented by Nonhebel and Raats (2007), wherein quorn was observed to be more efficient in the use of nitrogen and sugar, but required more energy inputs. No other impacts in this study were considered. Sonesson, Mattsson, Nybrant, and Ohlsson (2005a) used LCA to compare three ways of preparing a whole meatball meal, and Davis and Sonesson (2008b) quantified the environmental improvements for two different chicken meals. Baroni, Cenci, Tettamanti, and Berati (2006) compared conventional, vegetarian, and vegan diets, and concluded that decreased meat consumption was beneficial for most environmental impact categories, most prominently for land use. A second assessment of dietary environmental impact was presented by Wallèn, Brandt, and Wennersten (2004), wherein a 'sustainable diet' was compared to the average food consumption in Sweden. In contrast to Baroni et al. (2006), the result showed only minor improvements in the global warming potential by changing the average Swedish diet, a conclusion heavily affected by the exclusion of emissions of methane and nitrous oxide, which generally account for more than 50% of food-related greenhouse gas emissions. Carlsson-Kanyama, Pipping Ekström, and Shanahan (2003) presented a similar study, wherein energy usage from food production and the connections to consumption patterns were analysed. A framework on how to analyse different diets from health, economic, and environmental perspectives was presented by Duchin (2005), wherein a combination of LCA and input–output analyses of scenarios were key elements.

The aforementioned studies all address the question of how choices of meals or diets affect the environmental impact of food consumption; however, they do not address the question of what the impacts of different protein sources are, including different ways of producing and processing the same type of protein. In the present study, we examine, using LCA, four different ways of delivering proteins in a meal, covering both the aspect of raw material sources and processing alternatives. The alternatives studied include, replacing soya with grain legumes in animal feed, replacing part of the meat with pea protein in a processed meat product, and finally replacing meat with peas.

1.1. Aim and objectives

- *Aim*: To increase the understanding of the environmental implications of different meal compositions, with a focus on protein source.
- *Objective*: To compare the impacts on the environment from four meals with different protein sources in two countries.

2. Studied systems

Food has many functions for humans, supplying nutrients, such as energy, proteins, and vitamins, but also offering pleasure, culture, and social identity. We have chosen the function of food as a basic nutrient supply in this study; hence, the functional unit of the study is one meal served at the table in a household, in two different countries, Sweden and Spain. The reason for placing the case studies in two different countries was not to compare the countries, but to highlight how the results and improvement potentials depend on the surrounding systems, thus investigating both general and specific aspects.

The study includes four meals with different amounts of soybeans or peas (either as feed for pork production or directly consumed):

1. *SOY pork chop* Pork chop produced with conventional feed (SOY = pig feed based on soyabean meal imported to Europe and cereals), potatoes, raw tomatoes, wheat bread, and water.
2. *PEA pork chop* Pork chop produced with alternative feed (PEA = pig feed based on peas, rape seed, cereals mostly grown in Europe, and some imported soyabean meal), potatoes, raw tomatoes, wheat bread, and water.
3. *Sausage partial PEA* Meal with partial replacement of pig meat by peas; a sausage in which 10% of the animal protein is replaced by pea protein (the pork is produced with PEA feed), raw tomatoes, wheat bread, and water.
4. *PEA burger* Meal with full replacement of meat by a pea burger (the peas are grown in Europe), accompanied by raw tomatoes, wheat bread, and water.

The meals differ in the choice of protein source: Pig meat produced with contemporary protein feed largely based on soya bean meal, pig meat produced with peas grown in Europe, part of the meat replaced with peas, and finally a meal where all meat is replaced by peas. The composition of each meal has been put together so that each meal provides the same (or similar) amount of protein, energy, and fat, as well as with the intention that the overall size of the meal and the proportion between meal components are reasonable; see Fig. 1 and Table 1. Recommendations from the Swedish Food Administration on nutrient intake have been used to define the amount and proportions of the nutrients. The meals might not represent a typical meal that people normally eat, e.g., the amount of meat in the case study meals is probably less than what the average person normally eats in a meal, but this is because we seldom eat according to the health recommendations.

In the Spanish scenario, the peas, pork, wheat, and potatoes were produced in Spain, whereas in the Swedish scenario, the origin of these products were Germany, except for the potatoes, which were cultivated in Sweden. The tomatoes originated from Spain in both scenarios. The potatoes are either roasted in the oven (Spain) or boiled (Sweden). The pork chop, sausage, and pea burger are fried in a frying pan in both cases. In the Spanish case, 300 mL of mineral water is served with the meal, coming from a 1.5 L bottle.

In the Spanish scenario, the pigs were slaughtered at 105 kg, the feed conversion rate was 2.8 kg feed per kg weight gain, and there were 2.6 cycles per year. The pigs for the Swedish scenario had a slaughtering weight of 115 kg, the feed conversion rate was at 2.7 kg per kg weight gain, and there were 2.4 cycles per year. The production intensity in Spain is relatively low (Nemecek et al., 2008). The yield of peas was 1.2 t/ha with no use of mineral fertilisers. Wheat yield was 3.0 t/ha with fertiliser inputs of 80 kg $N ha^{-1} a^{-1}$, 72 kg P_2O_5 $ha^{-1} a^{-1}$, and 24 kg K_2O $ha^{-1} a^{-1}$. Peas produced in Germany had a yield of 3.3 t/ha with 54 kg P_2O_5 $ha^{-1} a^{-1}$

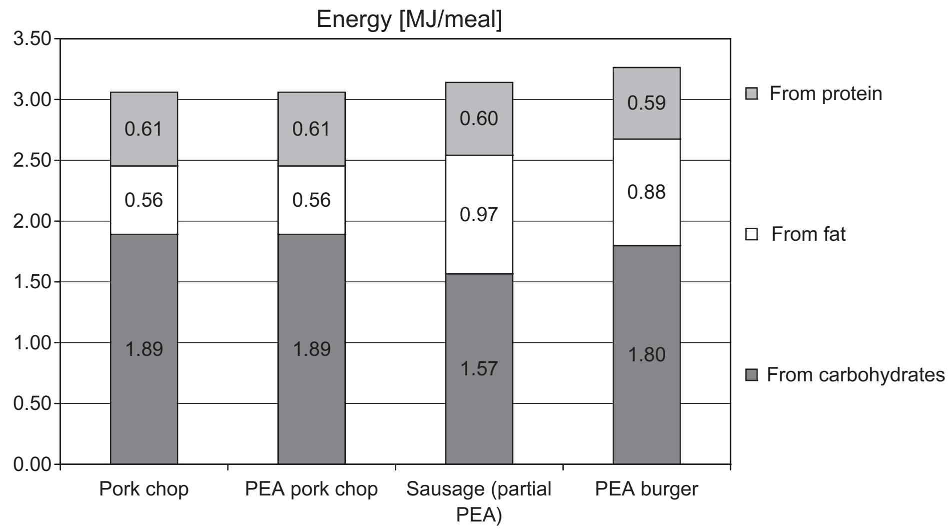

Fig. 1. Amount of energy in each meal, and contribution to energy from protein, fat, and carbohydrates, respectively, (nutritional data for pork based on a pork chop with a 5 mm fat rind).

Table 1
Amount of ingredients and overall protein content of each meal (g or mL per meal).

Meal	Pork chop/sausage/burger (g)	Potatoes, peeled (g)	Tomatoes (g)	Bread (g)	Water (mL)	Protein content (g)
SOY pork chop	100[a]	350	90	100	300	34.8
PEA pork chop	100[a]	350	90	100	300	34.8
Sausage partial PEA	225	–	90	140	300	34.7
PEA burger	275	–	90	80	300	33.7

[a] Weight without bone, but with a 5 mm fat rind.

and 44 kg K_2O ha^{-1}a^{-1}. German wheat had a yield of 7.6 t/ha with use of 172 kg Nha^{-1}a^{-1}, 54 kg P_2O_5 ha^{-1}a^{-1} and 23 kg K_2O ha^{-1}a^{-1}. The pea and wheat crops were considered as being part of a crop rotation (data from Nemecek et al., 2008). The pre-crop effects were considered by accounting for the nutrients received from the pre-crop and the nutrients delivered to the following crops. Soya bean production of Brazil and the USA did not differ much in intensity, with yields of 2.7 t/ha and with fertiliser inputs of 30 kg P_2O_5 ha^{-1}a^{-1} and 30 kg K_2O ha^{-1}a^{-1} for Brazil, compared to yields of 2.9 t/ha with use of 4 kg Nha^{-1}a^{-1}, 12 kg P_2O_5 ha^{-1}a^{-1}, and 22 kg K_2O ha^{-1}a^{-1} in the USA, while a relevant difference occurs in terms of deforestation, which occurs in Brazil but not in the USA. For the pork in the Swedish meals, the soya bean meal for pig production came in equal parts from Brazil and Argentina. In the Spanish case study, the soya bean meal originated from Brazil and the USA.

Carbon release from land transformation has been taken into account for soya bean meal originating from Brazil and Argentina. We considered CO_2-releases from biomass burning and from soils during cultivation according to Jungbluth et al. (2007). In Brazil, 3.2% of the soya bean cultivation area is transformed from rainforest yearly, while in Argentina, 1.6% of the cultivation area is transformed from savannah (for further information see Baumgartner, de Baan, & Nemecek, 2008).

3. Method

The analysis was conducted following established LCA methodology. For further information on LCA, see e.g., Baumann and Tillman (2004). This method starts with defining the system to be studied and the purpose of the study. System boundaries are then chosen, stating where the life cycle starts and ends, as well as which activities are included and excluded in the analysis. In this study, the analysis starts with raw material production in agriculture, including production of inputs, such as fertilisers and fuels. All inputs of packaging materials for the products are included, as is the waste management of the used packaging, see Fig. 2. Production of electricity and heat, as well as water used in the system, is included. Electricity for storing and cooking in households is included, as well as all transport involved throughout the chain. Finally, the environmental impact from sewage treatment, including both the process and the outgoing water from the treatment plant, is included in the analysis. This means that the environmental impact of nutrients contained in the food is followed back to the ecosphere, which was recommended by Sonesson, Jönsson, and Mattsson (2004) for comparative LCAs where the nutrient content in the compared products differ.

Once the system is defined, the data inventory is collected, i.e., data is gathered about the resource use, energy consumption, emissions, and products resulting from each activity in the production

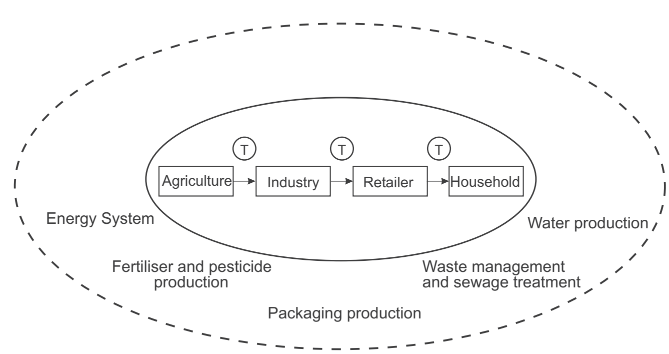

Fig. 2. Activities/processes included in the analysis.

chain. All in- and out-flows are then calculated on the basis of a unit of the product called the functional unit (here: A meal served at the household). For some activities, more than one product may be the outcome. In such cases, the total environmental impact is often divided between the main product and by-products, a procedure known as allocation in LCA methodology. Here, we have used the economic value of the outputs to allocate the environmental burden between co-products (e.g., grinding of wheat, which gives both flour and bran). Regarding the data sources for the analysis, data for pork production, wheat, and peas have been taken from Baumgartner et al. (2008). For other materials, data from literature and life cycle inventory (LCI) databases have been used, primarily Ecoinvent Centre. (2006). For industrial operations, e.g., the production of sausages and pea burgers, industrial contacts in Sweden and Spain have provided data. All the data and data sources used in the analysis are given in Davis and Sonesson (2008a). Some key inventory data are reported in Tables 2–4. The electricity use in the abattoir is quite different for the two countries; the reason for this difference is not clear, but can be attributed to different practices. Both sets of data originate from data collected from actual slaughterhouses. We assume that waste from the slaughter process (fat and bones) is incinerated. Even if this is not always the case, e.g., meat and bone meal can also be used as fertiliser, it is still a reasonable scenario for treatment of abattoir waste. Regarding consumer transport between the shop and the household, this is based on a Swedish survey (Sonesson, Antesson, Davis, & Sjödén, 2005b), which gives information on how far a household, on average, drives per week with the sole purpose of food shopping (trips made by foot, bike or bus have been assigned zero impact). Regarding the treatment of the waste water from the household (after the food has been eaten), we have used the protein content of each meal to calculate the energy use and also the emission of nitrogen at the waste water treatment plant. The correlation between weight of protein to the weight of nitrogen contained in the protein is about 6.25. Since, over time, we excrete the same amount of nitrogen as we take in, most of the nitrogen in the meals ends up in the waste water. We have assumed that 50% of the nitrogen is removed at the plant and that 40 MJ electricity/kg nitrogen removed is used, based on Dalemo (1996).

The first result of an LCA is a matrix of inventory results, where the calculated values for each phase of the life cycle and also the total values are presented for a number of categories of substances, like resources from the ground, resources from water, emissions to air, emissions to water, and products. In order to simplify this table and to get an idea of what kind of environmental impact the emissions cause, impact assessment methods are used which weigh together all emissions causing, for example, global warming potential, acidification, eutrophication, etc. The following impact categories have been considered in this LCA study based on that they are important when it comes to food production systems: The use of renewable (biomass, wind, and water) and non-renewable (fossil and nuclear) energy resources according to ecoinvent methodology (Frischknecht et al., 2003), global warming potential (time horizon of 100 years; carbon dioxide from fossil sources and land transformation, e.g., for soya bean production, was accounted for but not carbon dioxide from biogenic sources) according to IPCC. (2001), photo oxidant formation potential (as precursors of ozone), evaluation for high NO_x areas using method EDIP97 (Hauschild & Wenzel, 1998), stratospheric ozone depletion potential, and eutrophication and acidification potentials according to Hauschild and Wenzel (1998).

Ecotoxicity and human toxicity potentials have not been taken into account in this study. We have not been able to attain the required information concerning the use of pesticides in all of the agricultural products that are used in the meals, therefore these impacts have not been considered here. For information concerning the impact on toxicity from increased use of European produced grain legumes, we refer to Baumgartner et al. (2008).

Table 2
Data used for the slaughterhouse per kg of produced pork (bone free).

	Germany (Anonymous. (2002))	Spain (Lafargue (2007))
Water consumption (l)	5	27
Part of carcass weight to residual treatment (%)	40	40
Oil for heating (MJ)	1.14	3.40
Electricity (MJ)	2.87	7.43
Secondary packaging added, LDPE (g)	4.5	4.5
Secondary packaging added, corr. cardb. (g)	29.6	29.6

Table 3
Data on inputs and emissions from the sausage manufacturing process (chilled end-product) (Abelmann, 2005).

	Per kg sausage
Inputs:	
Electricity (MJ)	1.29
Light fuel oil (MJ)	0.65
Biofuel (MJ)	0.65
District heating (MJ)	0.43
Packaging, LDPE (g)	2.48
Packaging, PP (g)	0.48
Packaging, PA (g)	0.84
Emissions to water:	
N (g)	0.17
P (g)	0.05
COD (g)	7.83
BOD (g)	3.72

Table 4
Data on inputs and energy use for the production of pea burger (frozen end-product) (Gratschev, 2006, pers. comm.).

	Per kg burger
Inputs:	
Peas, dried (g)	440
Potato starch (g)	16
Rape seed oil (g)	90
Water (g)	454
Packaging, cardboard (g)	30
Energy use:	
Electricity (MJ)	2.95
Electricity for production of liquid nitrogen (MJ)	4.5

4. Results

The labels in the result figures below refer to the following processes/activities: *Household*: Cooking and household waste water treatment; *Consumer transport*: The transport with car between the retailer and household; *Truck transport*: All truck transport between the farm, industry, and retailer (truck transport for farm inputs are included in the farming categories); *Retailer*: Storage at the retailer; *Packaging*: Production and waste treatment of all packaging; *Industry*: Abattoir, mill, bakery, sausage production, pea fractioning, pea burger production, mineral water production; *Wheat/potato/tomato farming*, *Pea farming*, and *Pig farming including feed*: Farming, including the production of fuels, fertilisers, pesticides, and feed; *Abattoir waste treatment*: Incineration of abattoir waste.

4.1. Energy use

Figs. 3 and 4 show the uses of primary energy (non-renewable and renewable) for the Swedish and Spanish meals, respectively. The energy use for all four meals in each scenario is within the same order of magnitude, but the overall energy use is higher in the Spanish case, which is mostly due to the energy needed in the household to roast the potatoes in the oven (in the Swedish case, the potatoes are boiled). Moreover, in the Spanish scenarios, 1.3 MJ is required to produce the plastic bottle for the mineral water, and the contribution from the pig farm is also higher compared to the Swedish meals.

There is no significant difference between the two pork chop meals because the substitution of soya bean meal is not achieved simply by replacing peas. Peas provide not only protein, but also energy in the feedstuffs, which means peas partly replace energy-rich feeds, such as cereals. Thus, the composition of the entire formula changes, meaning, in the case of PEA, there is less energy needed for overseas transport and production of energy-rich feeds, but this is compensated by an increased amount of energy needed for production of peas and other protein rich feeds (for further information see Baumgartner et al., 2008), as compared to SOY.

The energy demand of the pea burger meal is as high as that of the other meals because we have assumed the pea burgers are sold as a frozen product; hence, a lot of energy is used for freezing it at the site of industry and then storing it in a freezer, both at the retailer and at the household (there is also more energy needed for frying the burgers at the household, as the amount of burgers is higher than the amount of pork chop).

4.2. Global warming potential

Fig. 5 shows the contribution to the global warming potential for each of the Swedish meals. When comparing the two pork chop meals, there is very little difference between pork that has been produced with soya bean-based feed and pork produced with feed

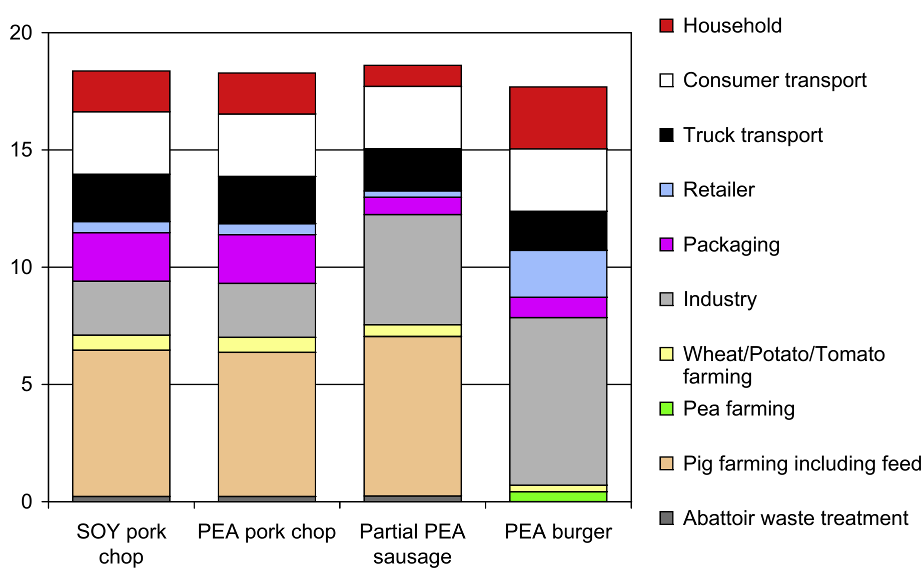

Fig. 3. Use of non-renewable and renewable energies for the Swedish meal scenarios (MJ-eq/meal).

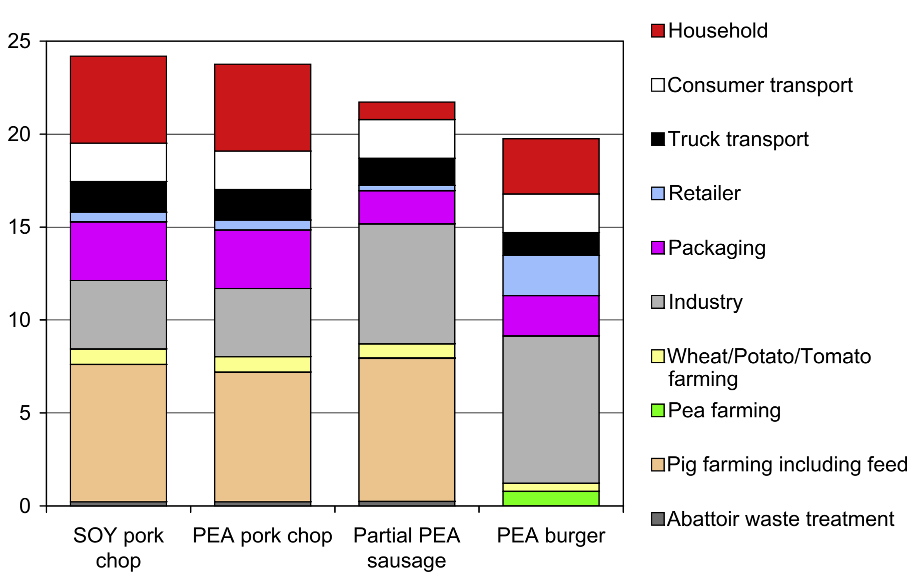

Fig. 4. Use of non-renewable and renewable energies for the Spanish meal scenarios (MJ-eq/meal).

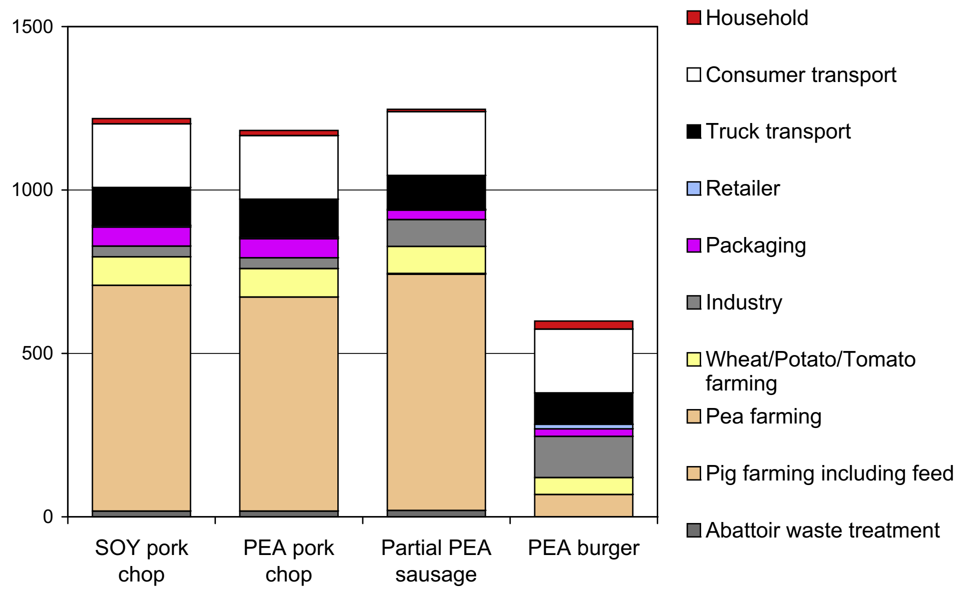

Fig. 5. Global warming potential (100 years) for the Swedish meal scenarios (g CO_2-eq/meal).

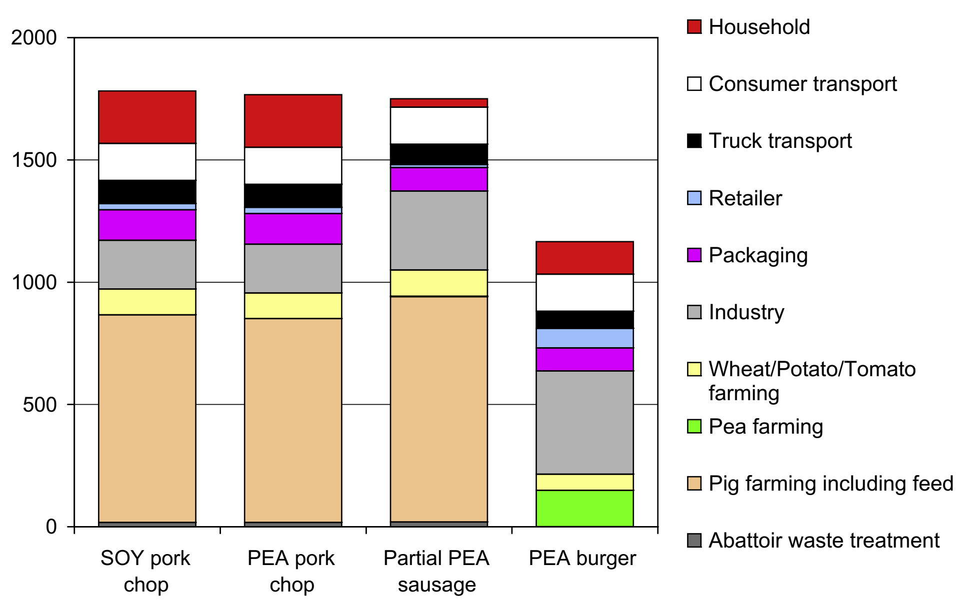

Fig. 6. Global warming potential (100 years) for the Spanish meal scenarios (g CO_2-eq/meal).

based on peas from Germany, for reasons explained above. The PEA pork chop has only a slightly reduced global warming potential, which is due to resultant deforestation from soya bean cultivation included in the SOY pork chop scenario.

The meal with sausage has a higher contribution to the global warming potential than the pork chop meals. This results from the fact that all meals must contain similar amounts of protein and energy. The amount of pork must be higher in this meal compared to the pork chop meals in order to satisfy these requirements. The pork chop meals contain a lot of potatoes in order to fulfil the recommended levels for energy content of a meal. The amount of sausage has to be as high as it is in the sausage meal to achieve the same level of protein as in the pork chop meals (which contain protein from both pork and potatoes). The contribution from pea production for the pea protein in the sausage meal is negligible, so one way of decreasing the impact from the sausage meal would be to increase the share of pea protein in the sausage (which is only 10% of the total protein in the sausage in our case), but this was discarded for reasons of sensory quality.

The vegetarian pea burger meal has a much lower contribution to the global warming potential than the meals containing animal protein. The consumer transport, i.e., the transport between the shop and the household, contributes significantly to the global warming potential.

The results for the Spanish meals shown in Fig. 6 are similar to the Swedish meals, in that the internal correlation between the meals is the same, but the overall contributions are higher compared to those of the Swedish meals. The reason for this is partly because a higher amount of electricity is needed for roasting the potatoes (in the Swedish case, they are boiled), and partly due to the electricity mix in Spain. Electricity production in Spain is based, in part, on coal combustion, and hence, as the figure shows, industry and households are significant contributors to the global warming potential. On the other hand, in Sweden, the electricity mix is based primarily on nuclear and hydropower, which contribute very little to the global warming potential. Since the pea burger meal requires significant amounts of electricity at the pea burger plant, retailer, and household, the contribution is higher in the Spanish scenario compared to the Swedish scenario (due to the difference in electricity mix), but the contribution is still only two thirds of that of the meals with animal protein. This is why the contribution to the global warming potential remains low despite a significant amount of energy being used for producing the pea burger meal.

4.3. Eutrophication potential

The contributions to eutrophication for the four analysed meals are shown in Figs. 7 and 8, wherein the production at the farm stage and waste water treatment from the household are shown to largely determine the impact, and that the total contribution from all other stages is quite small. The level of protein is very similar in all four meals in each scenario, resulting in similar contributions from sewage treatment (included in 'Household'). Overall, the contribution from the meals containing animal protein is much higher than the vegetarian meal. For the Swedish meals, again, there is very little difference between the two pork chop meals, even though the feed compositions for the pigs are different; however, in the Spanish scenario, the contribution of the pork produced with pea-based feed is higher than that of the soya bean-based pork. The reason for this is primarily due to nitrate leaching from the cultivation of peas. There is a higher incorporation of peas in the PEA formula in the Spanish scenario (18% of formula compared to 10% in the Swedish scenario), and the yield level of peas in Spain is comparatively low due to water limitations and generally more extensive management. The majority of the contribution from the pig farms comes from the release of nitrate and ammonia (housing, manure spreading, and piglet production; for further information see Baumgartner et al., 2008).

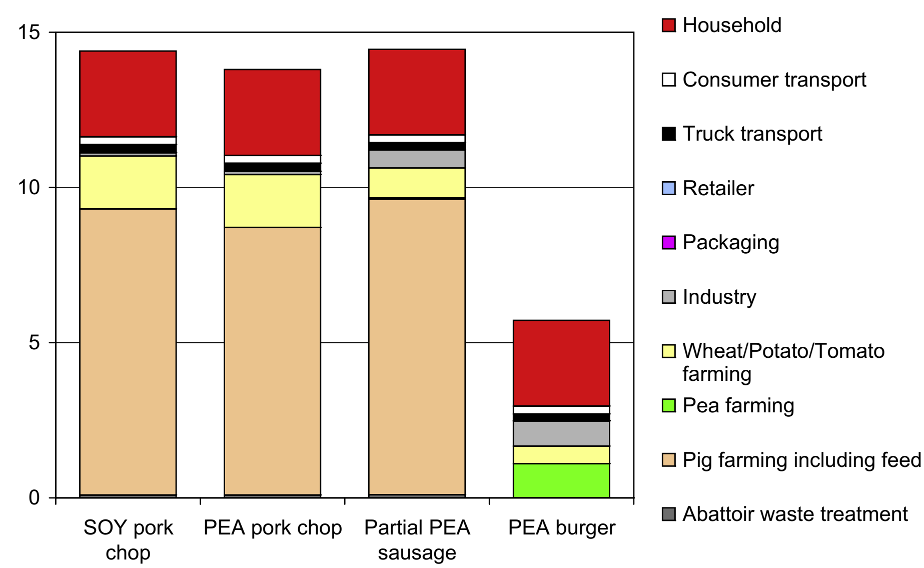

Fig. 7. Eutrophication potential for the Swedish meal scenarios (g N-eq/meal).

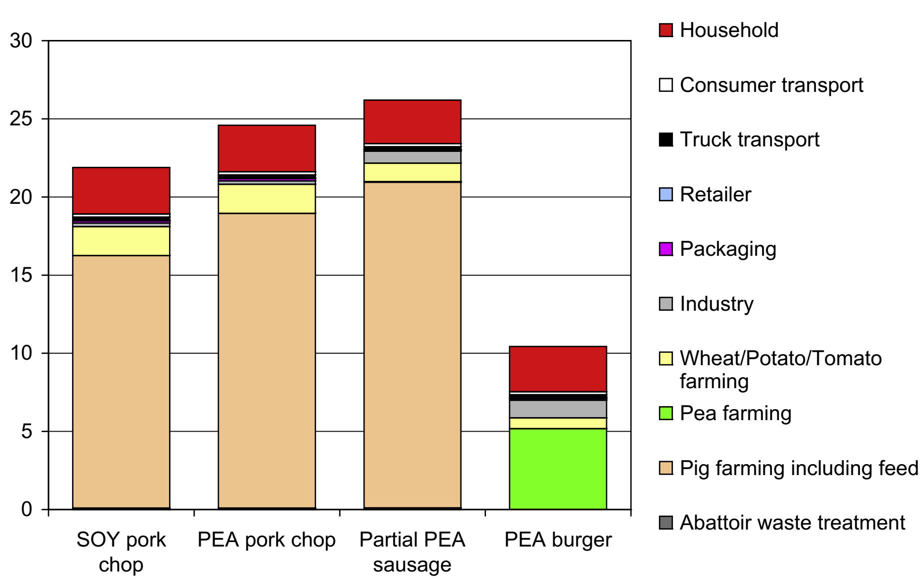

Fig. 8. Eutrophication potential for the Spanish meal scenarios (g N-eq/meal).

Table 5
Results for Swedish meal scenarios: impacts for one meal.

	Pork chop	PEA pork chop	Sausage partial PEA	PEA burger
Non-renewable energy resources, fossil and nuclear (MJ-eq)	1.30×10^{1}	1.29×10^{1}	1.32×10^{1}	1.12×10^{1}
Energy resources, non-renewable and renewable (MJ-eq)	1.78×10^{1}	1.77×10^{1}	1.82×10^{1}	1.61×10^{1}
Global warming potential (GWP) (kg CO_2-eq)	1.19×10^{0}	1.15×10^{0}	1.22×10^{0}	5.40×10^{-1}
Photochemical ozone creation potential (POCP) (kg ethylene-eq)	9.10×10^{-4}	9.10×10^{-4}	9.50×10^{-4}	7.30×10^{-4}
Stratospheric ozone depletion (kg CFC-11-eq)	6.00×10^{-8}	6.00×10^{-8}	7.00×10^{-8}	5.00×10^{-8}
Eutrophication (kg N-eq)	1.44×10^{-2}	1.38×10^{-2}	1.44×10^{-2}	5.70×10^{-3}
Acidification (kg SO_2-eq)	1.11×10^{-2}	1.08×10^{-2}	1.17×10^{-2}	2.38×10^{-3}

4.4. Summary of environmental impacts

The results from all impact categories considered in the study are summarised for the Swedish meals in Table 5. Overall, the results for the two pork chop meals are very similar, while the results for the sausage meal are slightly higher due to the higher content of pork in this meal. Furthermore, the impact for the vegetarian meal is much lower than for the meals with animal protein, with the exception of energy use, as explained earlier. With regard to the contribution to the global warming potential, eutrophication potential, and acidification potential, the pea burger meal has a significantly lower impact than the meals with animal protein.

The results for the Spanish meals are summarised in Table 6. Overall, the results for the two pork chop meals are similar for most of the impact categories, while the pork produced with feed based on peas has a higher impact than the one produced with soya-based feed on eutrophication. The impact for the vegetarian meal is lower, for most categories considerably lower, than the impact of the other meals.

5. Discussion

5.1. Difference between protein sources

The study shows that vegetarian meals are associated with less environmental impact than meals with animal protein, wherein eutrophying and acidifying emissions, as well as greenhouse gas emissions, are much lower; however, concerning energy use, vegetarian meals require about the same amount of energy as the meals with animal protein, which is due to the greater energy demands of industrial pea burger processing (primarily from freezing the product). The representative data used in this study for the pea burger processing energy requirements come from a relatively small-scale plant in Sweden, which means there is a potential for energy savings that needs to be further explored. The choice to study a frozen vegetarian product also affects the results, that is, with increased consumption, chilled products might become more common, resulting in lower energy usage in industrial processing. Furthermore, we have assumed the pork chop to be bought fresh, which is the most common way to buy this type of meat; however, a lot of meat is also sold already frozen in the form of ready-made meals, cuts of meats, and burgers, therefore, the need for energy efficient freezing and storage also applies to these types of products.

In this study, the pea-based meal contained a product that replaced the meat product in a meal, i.e., it looks and tastes similar to a meat product; however, there are other ways of consuming peas that require less processing, e.g., dried peas cooked in a stew or soup at home. The environmental impact of such a meal might be lower at the industrial stage, but higher at the household stage (long cooking time), and needs to be further explored.

Land use is considerably lower for the vegetarian meals, simply due to the fact that a large amount of vegetable protein is needed to produce animal protein. It is more efficient to directly eat grain legumes rather than first feed them to an animal that is later consumed. Efficient land use is central in sustainable development. The resource of arable land is likely to become even more valuable in the future as the global population grows, which in turn increases global meat consumption due to improved economic welfare. Furthermore, the demand for bio-energy and the arable land required therein is likely to increase as the price of oil increases.

In the sausage meal, part of the animal protein was replaced by pea protein; however, compared to the pork chop meals, the sausage meal still had a higher environmental impact due to the amount of sausage required to cover the protein needs of the meal. Hence, in this study, it proved much more environmentally beneficial to produce a fully vegetarian meal than to partly replace animal protein with pea protein. Still, the pea protein in the sausage had a very small contribution to the overall environmental impact of the sausage meal, so if a larger part of the animal protein can be replaced, say, 50% of the animal protein instead of the 10% we assumed, the environmental impact of the sausage meal would probably be lower than the meals with pork chops; however, this would alter the sensory experience of the sausage. Further work is needed to explore the feasibility of exchanging animal protein with vegetable protein in processed meat products.

The fact that the sausage meal was slightly worse in terms of environmental impact than the other meals proves that choosing a meal as the functional unit, as opposed to single food products, was the right decision. In the pork chop meals, potatoes needed to be added to match the carbohydrate levels in the other meals (the sausage and pea burger contain high levels of carbohydrates), and potatoes also contain some protein, resulting in more sausage being needed in the sausage meal to match the protein level of the pork chop meals. This is something we would have missed if only

Table 6
Results for Spanish meal scenarios: impacts for one meal.

	Pork chop	PEA pork chop	Sausage partial PEA	PEA burger
Non-renewable energy resources, fossil and nuclear (MJ-eq)	2.24×10^{1}	2.20×10^{1}	2.04×10^{1}	1.77×10^{1}
Energy resources, non-renewable and renewable (MJ-eq)	2.44×10^{1}	2.40×10^{1}	2.19×10^{1}	2.02×10^{1}
Global warming potential (GWP) (kg CO_2-eq)	1.77×10^{0}	1.76×10^{0}	1.74×10^{0}	1.16×10^{0}
Photochemical ozone creation potential (POCP) (kg ethylene-eq)	9.10×10^{-4}	9.20×10^{-4}	9.60×10^{-4}	6.70×10^{-4}
Stratospheric ozone depletion (kg CFC-11-eq)	1.00×10^{-7}	1.00×10^{-7}	1.00×10^{-7}	5.00×10^{-8}
Eutrophication (kg N-eq)	2.19×10^{-2}	2.46×10^{-2}	2.62×10^{-2}	1.04×10^{-2}
Acidification (kg SO_2-eq)	2.18×10^{-2}	2.15×10^{-2}	2.16×10^{-2}	9.98×10^{-3}

single food products were studied (i.e., comparing the sausage to the pork chop). Furthermore, presenting the results per meal facilitates communication of the results, as they are easy to interpret and put into a context; however, regarding the pork in the pork chop and sausage meals, we have not allocated the environmental burden to different meat products of the animal, i.e., all burden has been assigned to one product encompassing all qualities: Bone free meat. This means we have assumed the same environmental burden per kg of pork in the pork chop meals and the pork in the sausage meal. If one were to assign a higher burden to the meat with lower fat content or meat of higher quality, then the burden of the pork chop meal would increase accordingly just as it would decrease for the sausage meal. It is important to recognise that there are environmental benefits of making use of all parts of the animal since significant agricultural inputs have gone into producing it, and that producing sausages is one way of making use of meat that would otherwise not be consumed. In order to take this into account, there is need for work on how to partition the environmental load between different parts of the animal.

5.2. Effect of country scenario on the results

The production of electricity proved to be an important difference between the meals in the Swedish scenario and Spanish scenario. Swedish electricity production is primarily based on nuclear and hydropower (90%), and eutrophying, acidifying, and greenhouse gas emissions are very low from these power sources, although there are other environmental concerns associated with these technologies, in particular regarding the radioactive waste from nuclear power. This means that products that use a lot of electricity are less burdened with emissions. In our case, this favours the sausage and especially the pea burger meal. In contrast, the Spanish electricity mix is primarily based on coal, nuclear, and hydropower, resulting in higher emissions. Here, the contribution of the pea burger meal is relatively higher than that of the Swedish scenario, but is still substantially lower than the meals with animal protein.

Apart from the difference in electricity production, the main distinction between the Swedish and Spanish scenarios is due to the difference in environmental impact of producing peas and pork. In general, the impact is higher in Spain compared to Germany. This is due to the comparatively low yield levels of peas, and in addition, for pork production, the high level of pea incorporation, as well as the higher share of imports and the lower conversion rate of feed to meat disfavour the results for PEA in Spain. Another significant difference is at the household level. In the Spanish scenario, the potatoes are oven baked, which is more energy demanding than the boiling of potatoes in the Swedish scenario. If the potatoes were fried instead (another feasible scenario, particularly in the Spanish case), the energy use would be slightly less per portion than when boiling them.

5.3. Functional unit of study

When undertaking comparative LCA studies, the definition of the functional unit is crucial. The four meals that have been compared for each country scenario are equal when it comes to the basic function of providing nutrition; however, they are not the same when considering other properties like taste. This is a methodological issue within LCA, to compare the environmental impact of products that provide slightly different functions. In order to deal with this, one function must be prioritised. In our case we have chosen the nutritional value of each meal, with a particular focus on protein and energy content. Ideally, a functional unit that encompasses all of the different properties of the meal would have been preferred, although this is difficult to accomplish.

5.4. Assumptions' effect on results?

Some assumptions made in the study might have an effect on the results. A substantial amount of potato waste is generated in the household (mainly from peeling the potatoes). We have not included the waste treatment of this flow in this study due to lack of data on how it is treated. For example, if the potato waste goes to incineration, heat is generated which gives the system an environmental benefit, while if the waste goes to landfill, this would generate a leakage of nutrient and form methane, which increases the environmental impact. When comparing the four meals, the omission of this waste treatment means that the environmental impact of the pork chop meals is either overestimated or underestimated, depending on which waste treatment method is used; however, we still judge that this effect is too small to alter the overall comparison between the meals. The most important aspect when it comes to waste or resource efficiency is that it affects the amount of food that needs to be delivered from the farm in order to provide a certain amount on the dinner table; hence, significant waste means that the environmental impact has been unnecessarily caused at the farm.

Consumer transport, i.e., the transport between the shop and household, significantly contributes to the global warming potential. The basis for this calculation is a survey that estimates the average distance driven by car per week for journeys that were made with the sole purpose of food shopping and also a separate figure for *all* trips for food shopping, some of which are combined with other errands. Here, we used the lower figure, i.e., not including the journeys that are combined with other errands; hence, it is quite possible this transport estimation is slightly underestimated. Consequently, reducing consumer transport would have a considerably positive effect on the overall environmental impact of a meal.

5.5. Increased consumption of peas on a large scale

The question of how a large scale transition to vegetarian diets would affect the environment and economics is extremely complex. Vegetarian meals require less arable land, so in this sense they are less resource-intensive. On the other hand, vegetarian meals can involve more processing, and thereby demand more energy. Furthermore, if the vegetarian diet contains many 'exotic' foods that are produced on other continents and require chilled transport or air-freight, then it is doubtful if this diet is more resource efficient than a traditional meat-based diet. Even if we assume that meat is primarily replaced by locally or regionally grown grain legumes, the consequences of a vegetarian diet are still not easily determined. The shift from animal production to arable farming with less agricultural value might also be less profitable. At the same time, the surplus of land (production of vegetable protein requires less land compared to animal protein) could improve the possibilities of increasing production of bio-energy (e.g., *Salix* for district heating), which will play an important role in efforts to reduce the dependency of fossil fuels and the global warming potential, and further, could also be a potential economic source for the farming community. A reduced production of milk and beef will decrease the farming of grass and clover, which can have negative consequences for soil fertility, since the growing of grass and clover is beneficial to the soil structure and also increases the level of organic matter in the soil; However, such effects could be overcome by growing crops that are then ploughed down into the soil, or by growing energy crops. These crops could then be harvested and used for producing bio-gas or for combustion. Another alternative is tree cropping (e.g., orchards) that yield a food source and help sequester carbon. Decreased consumption of pasture-based meats, such as beef, mutton, and lamb might also negatively impact biodiversity since many grazing fields are abundant with species (the 500,000 ha of grazing land in Sweden are amongst the most species rich ecosystems in Europe). Finally, a decreased consumption of more intensely raised meats, such as pork, poultry, and feed-lot beef would reduce the need for soya beans from tropical areas, and thereby preserve the biodiversity in rainforests that are otherwise exploited. Moreover, the production of these meats contributes very little to the biodiversity in the agricultural landscape where they are raised.

Conclusively, a substitution of grain legume protein for pig meat protein is probably positive from an environmental standpoint, provided that the vegetarian diets do not contain too much air-freighted, highly processed, and packaged vegetable components.

5.6. Improvement potentials for the different meals

Looking at the results of the three impact categories, energy use, global warming potential, and eutrophication potential, one can identify the importance of the following stages in the life cycle to the total environmental impact of the different meal scenarios: pig farming, pea farming in Spain regarding the pea burger meal, industry and household (particularly in the Spanish case). These are the areas in which improvement measures are best focused. Potential actions to reduce the environmental impact of the investigated meals are presented below, wherein the actions for pea and pig farming are taken from Baumgartner et al. (2008):

To reduce energy use and the global warming potential:

Pig farming:

- use local feedstuffs
- increase the use of food and agricultural by-products (e.g., liquid feeding)
- increase the feed conversion rate through breeding; the potential might not be that high anymore, but there is still a difference between pork produced in Germany and Spain
- environmental optimisation of feed formulas
- improve animal husbandry, i.e., reduce ammonia losses from pig keeping (to reduce indirect emissions of nitrous oxide, a potent greenhouse gas)

Industry:

- use more energy efficient cooling technology and pea burger production

Household, especially Spain:

- shift the energy generation method in Spain from fossil fuels to (more) renewable sources
- use more energy efficient cooking/frying/baking/roasting technologies
- use more energy efficient cooling technologies

To reduce eutrophication potential

Pig farming:

- improve yield levels of peas (especially for Spain)
- improve cultivation techniques of arable crops, namely of energy-rich feed crops
- improve manure management (e.g., covering of slurry lagoons)

Pea farming, in Spain:

- improve pea varieties for better yields
- use better suited (for Spanish conditions) grain legumes as sources for protein in veggie burgers

6. Conclusions

For most of the environmental impact categories considered in this study, the vegetarian pea-based meal has a significantly lower impact than the animal protein-based meals. This is the case in both the Swedish and Spanish scenarios; however, energy use is an exception. Here, the difference between the meals is small, which is mainly due to the processing, storing, and cooking of the pea product. The potential to develop more energy-efficient processing for pea-based food products needs to be explored.

This study also demonstrates that the environmental impact does not differ much between meats produced with different feed protein sources. Another conclusion is that the energy source (e.g., electricity production) plays an important role in the environmental impact of the meals.

In order to achieve any environmental gain of replacing animal protein with pea protein in meat products, more than 10% of the animal protein needs to be replaced. It is significantly more environmentally beneficial to provide a fully vegetarian meal than it is to replace 10% of the animal protein in a meal with vegetable protein.

The results developed in this study highlight the importance of using a life cycle approach, that is, it is not sufficient to only look at the impact from agriculture when comparing vegetable and animal foods.

6.1. Future research

Four different meals were analysed in this study. In order to better understand the environmental impact of meat and grain legumes meals further work should focus on:

- Assessing a meal based on pork produced from pigs that were fed with on-farm grown feedstuffs (e.g., FARM alternative in Baumgartner et al., 2008). In this scenario, transport is strongly reduced compared to the PEA and SOY alternatives.
- Exploring ways of increasing the replacement of meat protein with pea protein in meat products without compromising taste, and assessing a meal with a semi-vegetarian product consisting of a much higher plant protein content.
- Assessing a traditional grain legumes-based meal, e.g., split pea soup and potato-pea-stew.

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