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Climate change and dietary choices — how can emissions of greenhouse gases from food consumption be reduced?

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Results from an analysis of greenhouse gas emissions and energy consumption during the life-cycle of carrots, tomatoes, potatoes, pork, rice and dry peas consumed in Sweden are presented and discussed. The life-cycle is delineated to the part of the production chain prior to purchase by the consumer. The study shows that emissions, expressed in g CO_2 equivalents, are highest for pork and rice and lowest for potatoes, carrots and dry peas. The most important stages of emissions in the life-cycle are identified for each of the different food items. Crop farming is the most important stage for rice and tomatoes while rearing of animals is the most important stage for pork and storage is the most important stage for carrots. Comparison with an energy analysis shows that important stages in the life-cycle of food may be under-evaluated when energy only is accounted for. This may lead to a sub-optimisation of pollution control exemplified by the case of transportation. Also, it is shown that the choice of functional unit has a decisive influence on the outcome of the study. The recommendation is to compare whole meals, or diets with the same nutritional qualities. A comparison of four meals composed of the food items under analysis shows that a meal with tomatoes, rice and pork has nine times higher emissions than a meal made from potatoes, carrots and dry peas. Emissions of greenhouse gases from consumption patterns based on the food items analysed are compared with an assumed sustainable limit of greenhouse gas emissions. The conclusion is that current food consumption patterns in the developed countries exceed the level of sustainability by at least a factor of 4. Prospects for achieving sustainable food consumption patterns are questionable in view of current trends in food demand.

Keywords: food consumption, climate change, life-cycle, food, greenhouse gases, sustainability

Introduction

Climate change has emerged as one the most controversial issues on the global environmental agenda. The recent Conference of the Parties to the Framework on Climate Change in Kyoto in December 1997 managed only, after threats of breakdown, to reach an agreement whereby the developed countries shall reduce their aggregate anthropogenic carbon dioxide equivalent

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emissions slightly during the next decade (United Nations, 1997)[1]. This agreement can be viewed with the perspective that the Intergovernmental Panel on Climate Change (IPCC) considers that accumulated emissions of greenhouse gases have already caused a global mean surface air-temperature increase of between 0.3 and 0.6°C during the past century, and 'that the balance of evidence suggests a discernible human influence on the global climate' (IPCC, 1996b, p. 4). The climate is expected to change with an average rate of warming greater than any seen in the last 10,000 years. The average sea level is expected to rise, some places are likely to experience more severe droughts and/or floods, and a sustained climate change could lead to a shift in the competitive balance among species. For any stabilisation of the levels of CO_2 in the atmosphere to occur, global anthropogenic carbon dioxide (CO_2) emissions will have to drop sharply as compared to the levels of 1990. A stabilisation of atmospheric concentrations of methane (CH_4) and nitrous oxide (N_2O) at today's levels would require reductions in anthropogenic emissions of 8% and more than 50% (IPCC, 1996a).

Emissions of the major greenhouse gases CO_2, CH_4, N_2O and hydrofluorcarbons (HCFCs) are closely associated with food production and consumption. During the life-cycle of food numerous human-induced activities cause emissions of these gases. For example, the use of fossil fuel in agriculture causes net emissions of CO_2 as the cultivation of organic soils often does. The fabrication and application of N-fertilisers causes emissions of N_2O. From the digestive tracts of cows, sheep and pigs, CH_4 is released. Refrigerants used in cold storage facilities often have a Global Warming Potential (GWP) and when leaked they contribute to climate change. Thus, food consumption directly and indirectly causes emissions of both energy related greenhouse gases and greenhouse gas emissions from other sources.

The consumption of food has been identified as one of the most resource demanding or polluting activities within a household (Vringer and Blok, 1995, p. 895, Table 2; National Consumer Agency, 1996, p. 11, Fig. 1; Wackernagel and Rees, 1996, p. 83). As food is a basic need, the dietary choices of individuals and households certainly are, and will continue to be, under close scrutiny during the search for sustainable consumption patterns. Food is not easily dematerialised and cannot be substituted for services, commonly proposed as ways to lessen the environmental impacts from consumption of other products than food (OECD, 1996). A change in diet is therefore one of the most important proposals for obtaining sustainable lifestyles in the developed countries.

Food consumption patterns are not only a reflection of nutritional needs, but also of preferences for taste, odour and texture as well as culture and ethics. Therefore, sustainable food consumption patterns not only have to be considered in regards to pollution and waste generation, but also for all their immaterial qualities as well as their cultural acceptance. Historically, patterns of food consumption have changed from a diet based mainly on locally produced foods to a diet where exotic fruits, vegetables and spices are commonplace. What was considered as an attractive diet some decades ago may today be considered as strange or even unpalatable by many young people. Future food consumption patterns will continue to be a reflection of overall lifestyles, income levels and values, but should also reflect a growing consideration for the state of the environment.

Although political leaders have shown a lack of affirmative action on curbing the rate of

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[1]The agreement was that the developed countries shall reduce their aggregate anthropogenic carbon dioxide equivalent emissions by no more than 5% below 1990 levels in the commitment period of 2008–2012. For the developing countries, and countries with transitional economies, no agreements on reduction targets were reached (United Nations, 1997).

climate change, local and individual attentions to more environmentally friendly lifestyles and consumption patterns are certainly increasing and encompassing initiatives that will, implicitly or explicitly, lessen emissions of greenhouse gases as a result of changed consumption choices. Examples of such initiatives are the household Eco-Teams within the framework of the Global Action Plan (GAP) and the Perspective Project in the Netherlands (GAP International, 1996; Perspective Secretariat, 1997) where households are encouraged to change their consumption patterns in order to reduce the consumption of energy and water and their production of waste. Although not large in scale at present, such programs could stimulate similar efforts on a larger scale. Moral support of such efforts can be found in several international declarations, as well as in Agenda 21. In Chapter 4 of Agenda 21, unsustainable consumption patterns in the developed world are targeted as an area for major concern and consumer information is given high priority (United Nations, 1992).

In this paper, I present a study with relevance to the issues mentioned above. Greenhouse gas emissions and energy consumption during the life-cycle of carrots, tomatoes, potatoes, pork, rice and dry peas consumed in Sweden have been calculated and the potential for changing food consumption patterns towards emission levels defined as ecologically sustainable are explored. The following questions will be addressed:

- What stages, or processes, during the life-cycle of food contribute significantly to the total emissions of greenhouse gases?
- How can a different functional unit[2] of food alter conclusions about environmentally sound food choices?
- What are the characteristics of food products which have low emissions of greenhouse gases during their life-cycle?
- To what extent is the level of emissions of greenhouse gases from present food consumption compatible with sustainable levels of emissions and what are the prospects for the needed adjustments?
- How does a greenhouse gas analysis of food compare with an energy analysis?

Materials and methods

Data

A detailed presentation of the data, methods and results used for the analysis of greenhouse gas emissions and energy consumption in the life-cycle of food is presented in Carlsson-Kanyama (1997, 1998). The results from the analysis of carrots and tomatoes were discussed in detail in Carlsson-Kanyama (in press).

System boundary

A life-cycle approach was used in all the studies. The analysis was delineated to the part of the production chain prior to the consumer's purchase of food. System boundaries were selected to facilitate comparisons between different food items. The system boundary for the vegetable

[2]The functional unit is the unit to which all results are related. Examples of different functional units for food may be a unit of weight or a unit of nutrients.

products (carrots, tomatoes, potatoes, rice and dry peas) is shown in Fig. 1 and the same boundary for the animal product in the study (pork) is shown in Fig. 2.

The calculations have included the following energy consumption and emissions of greenhouses gases:

- All energy consumption during the part of the production chain which is covered in the study (see Figs 1 and 2) was included. Pre-combustion energy consumption is included in

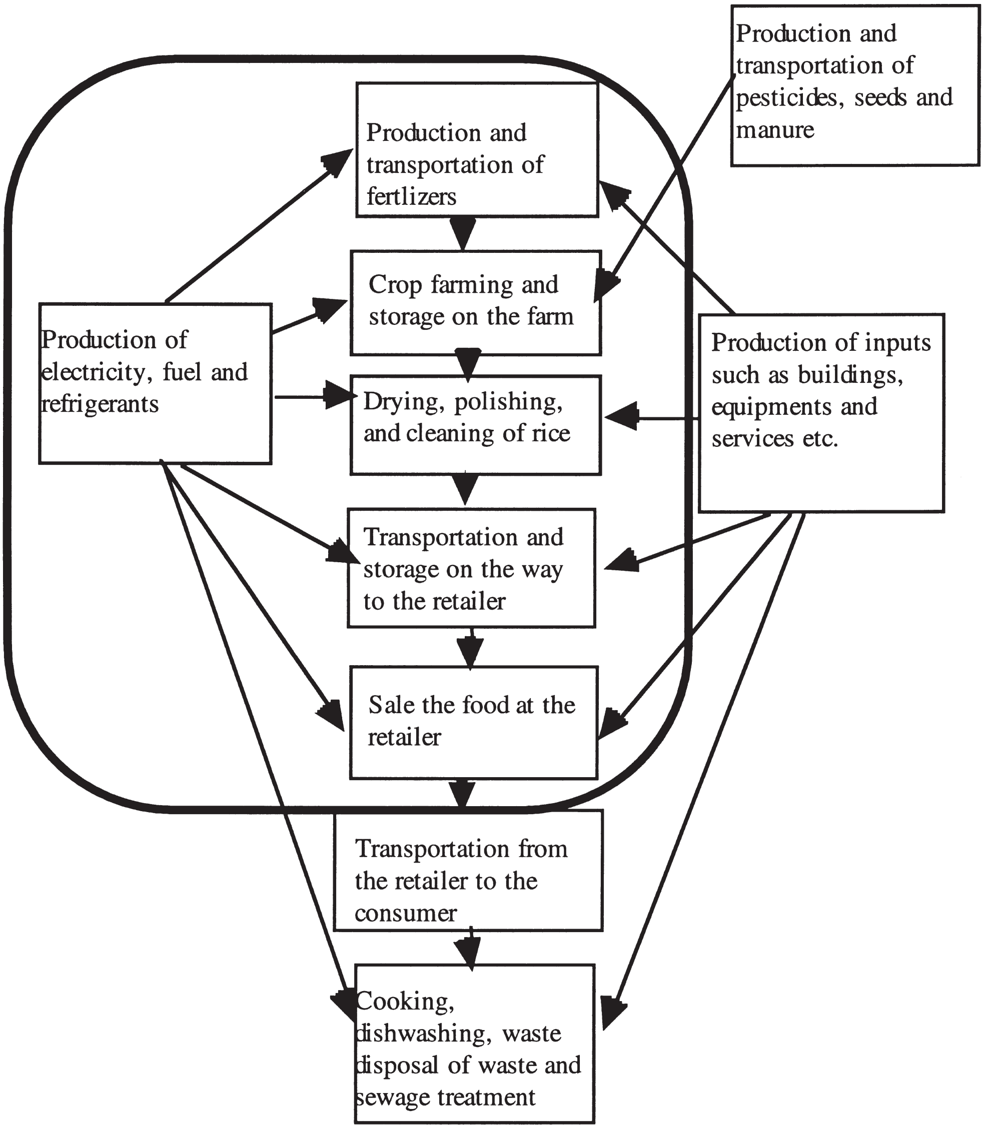

Figure 1 System boundary for the analysis of greenhouse gas emissions during the life-cycle of tomatoes, carrots, potatoes, rice and dry peas (thick line)

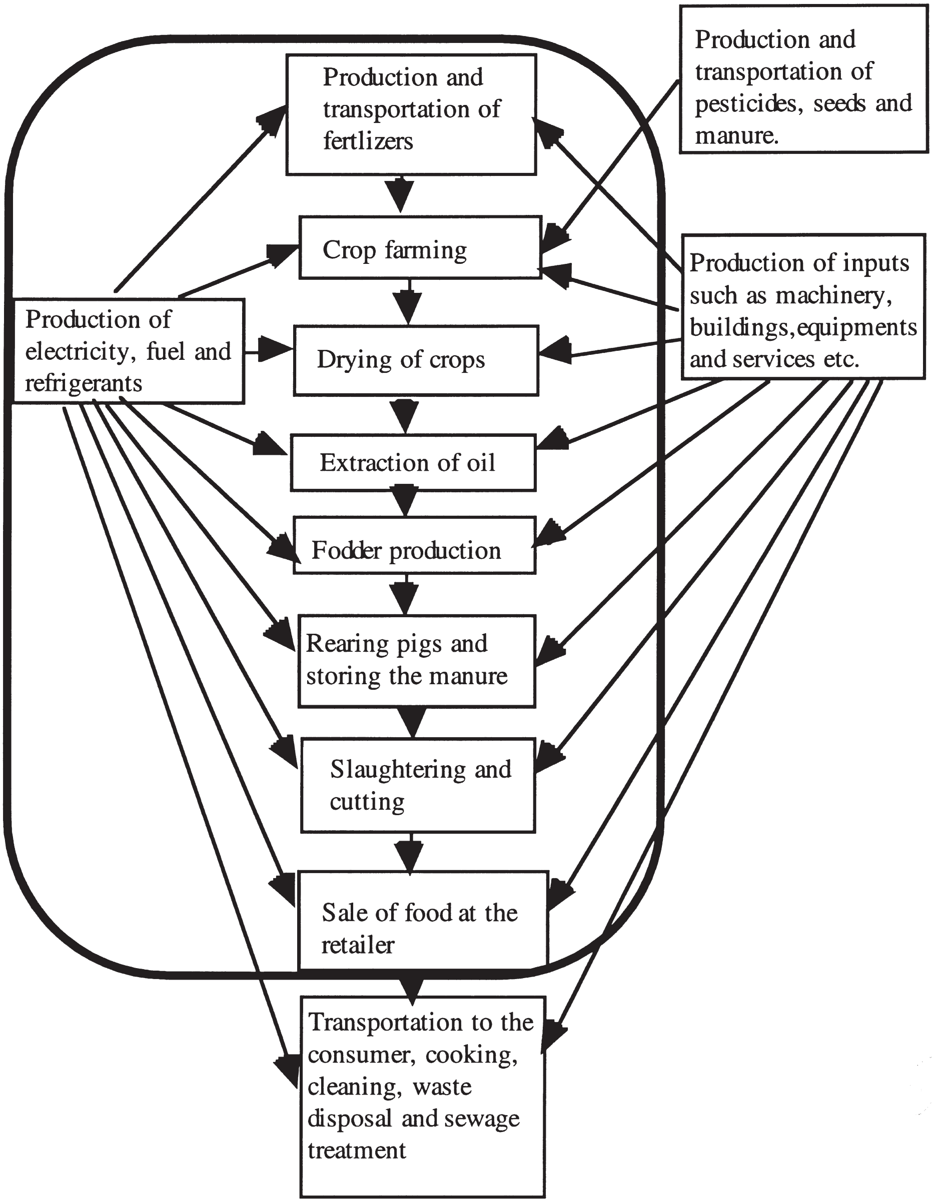

Figure 2 System boundary for the analysis of greenhouse gas emissions during the life-cycle of pork (thick line). Although not indicated in this figure, emissions occuring during transportation within the system boundary are included in calculations

the calculations except for electricity where figures include transmission losses but exclude losses during conversion.

- CO_2 fuel-cycle emissions from fuels used to run lorries, planes, ships, tractors, drying plants and fodder factories and generate the electricity used for storage, stables and electrical irrigation pumps are included. CO_2 emissions from the use of energy during the manufacturing and transportation of fertilisers are also included.

- Refrigerants leaking from transport refrigeration equipment in lorries, planes and ships and from refrigeration equipment in stationary storage facilities (storage rooms) are included. Production emissions of refrigerants are included as well.
- CH_4 emissions from rice fields and from the digestive tract of the pigs and their manure are included.
- Process emissions of N_2O during the manufacture of fertilisers and NO_2 emissions from farm land as a result of application of N-fertilisers were included. N_2O emissions during storage of manure were included as well.

All calculated emissions of the greenhouse gases mentioned above are re-calculated into g CO_2 equivalents using the Global Warming Potentials proposed by the IPCC (1996a, p. 22, Table 4).

Functional unit

The functional unit used in this study is one kilo of carrots, tomatoes, potatoes, rice, dry peas or pork sold by Swedish retailers during the early or mid-1990s. These foods items had many different countries of consumption origin (i.e. countries where the products were produced). The results presented here have been calculated as a weighted average of emissions per kg of food for all countries of consumption origin.

Results

Emissions of greenhouse gases and energy consumption differ greatly between the different food items analysed. Pork emitted nine times more greenhouse gases compared to dry peas and rice emitted 38 times more greenhouse gases than potatoes. The energy consumption for tomatoes was almost 15 times higher than for carrots. The most important stages in the life-cycle were, generally, crop farming and animal husbandry.

Total emissions

Table 1 shows the total greenhouse gas emissions and energy consumption for tomatoes, carrots, potatoes, rice, pork and dry peas. Both emissions of greenhouse gases and energy consumption were lowest for the vegetable products (carrots, potatoes and dry peas). These foods were grown in open fields and mainly in Sweden. Emissions of greenhouse gases were highest for rice and pork; the energy consumption was highest for tomatoes followed by pork and

Table 1 Emissions of greenhouse gases in CO_2 equivalents with a 20 year time perspective and energy requirements in MJ during the life-cycle of carrots, tomatoes, potatoes, pork, rice and dry peas consumed in Sweden. In g CO_2 equivalents per kg and MJ per kg. All emissions were supposed to occur at the same instant

	Carrots	Tomatoes	Potatoes	Pork	Rice	Dry peas
g CO_2 equivalents per kg	500	3300	170	6100	6400	680
MJ per kg	2.9	42	1.8	32	9.8	3.2

rice. Most tomatoes were assumed to be grown in greenhouses in Sweden or nearby countries, while rice was produced in countries distant from Sweden on irrigated fields.

Relative contributions of greenhouse gases during the different stages in the life-cycle of vegetable products

The relative contributions of the different stages in the life-cycle to the total emissions of greenhouse gases in CO_2 equivalents for the vegetable products analysed are shown in Fig. 3.

Emissions during crop farming were dominant for tomatoes, rice and dry peas, contributing to more than 80% of the total. The emissions were caused by different types of greenhouse gases, however. While almost all emissions during crop farming of tomatoes were caused by the combustion of fossil fuels in greenhouses, almost all emissions during crop farming of rice were caused by CH_4 from irrigated rice fields. It is important, however, to emphasise that the calculated emission levels of CH_4 from rice farming have substantial uncertainties associated. During crop farming of dry peas most of the emissions were caused by N_2O formation resulting from N-fixation by the crops themselves.

Emissions during storage contributed to over 60% of the total emissions for carrots while for the other foods analysed storage caused less than 10% of the total. The reasons for the large relative contribution of storage during the life-cycle of carrots are that carrots are commonly stored for a long time (several months) and also that they are cold-stored in facilities where leakage of refrigerants are known to occur. A different situation is found for potatoes, a food item stored over the whole winter in Sweden. Potatoes are cooled with air only during

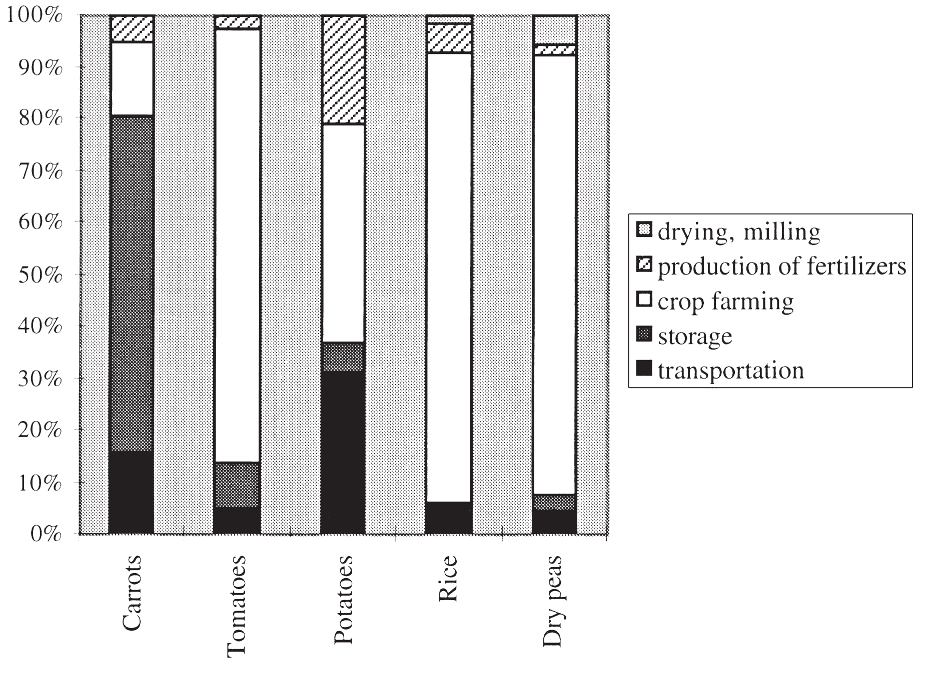

Figure 3 Distribution of greenhouse gas emissions during the life-cycle of carrots, tomatoes, potatoes, rice and dry peas. In CO_2 equivalents with a 20 year time perspective. All emissions were supposed to occur at the same instant

storage and therefore the relative contribution of storage emissions is much lower than for carrots.

Emissions during transportation were 16 and 31% of the total for carrots and potatoes, respectively, while for rice, dry peas and tomatoes transportation amounted to less than 10% of the total. Most of the carrots, all potatoes and all the dry peas were grown in Sweden, while all rice and 75% of the tomatoes were imported. Rice was mainly transported by ship while the main mode of transportation for tomatoes was lorry. All Swedish grown products were transported by lorry. Distances from the Swedish producer to the retailer were calculated to be 650 km for carrots and 370 km for potatoes, while the distance from the rice fields in the United States to the Swedish retailer was calculated to be 12,000 km. In absolute terms, emissions per kg of crop for transportation were 420 g of CO_2 equivalents for rice from the United States and 54 g of CO_2 equivalents per kg of potatoes. The reason for the large relative contribution of transportation in the life-cycle of potatoes as compared to rice is, of course, that other stages during the life-cycle were so different in magnitude.

Emissions during production and transportation of fertilisers contributed to less than 5% for carrots, rice, tomatoes and dry peas while it was 21% for potatoes. These emissions were mainly caused by the production and transportation of N-fertilisers.

Relative contributions of greenhouse gases during the different stages in the life-cycle of pork

The relative contributions from the different stages in the life-cycle of pork are shown in Fig. 4. The stages with the largest were rearing of the pig and crop farming of pig feed with 34 and 24% of the total emissions, respectively.

Emissions during crop farming were lowest for the cereals (wheat, barley and oat) with about 170 g of CO_2 equivalents per kg of crop harvested. For the nitrogen fixing crops in the study (dry peas and soya beans) emissions were 400–500 g of CO_2 equivalents per kg of crop harvested. The main reason for the higher emissions per kg of crops for the nitrogen fixating crops was the N_2O emissions related to fixation of nitrogen. However, the nitrogen fixed by such crops is beneficial later in the crop rotation, an effect not taken into account in this study.

Emissions during rearing of the pigs were mainly caused by CH_4 and N_2O emissions from the storage of pig manure, which is supposed to be stored in solid form. Seventy percent of the emissions during pig rearing can be attributed to manure storage. Only 3% of the emissions during pig rearing are caused by the use of electricity and fuel oil in the stables.

Emissions during production and transportation of the fertilisers (used for farming of the crops required for production of pig fodder) were 18% of the total, with N-fertiliser related emissions being the main contributor. Emissions during processing of fodder crops (drying of crops, oil extraction and fodder production) were 7% of the total. Emissions during processing were caused by energy utilisation only. Emissions during slaughtering were 2% of the total, while transportation contributed 5%. Storage of pork contributed 10%, with storage at the retailer as the major contributor.

Relative contributions of the different stages in the life-cycle of rice and pork to the total energy consumption

The relative contributions of the different stages in the life-cycle when it comes to energy consumption are shown for rice and pork only (Fig. 5).

Fig. 5 shows that the most energy demanding stages in the life-cycle of pork are crop farming and production of fertilisers. Rearing of pigs, the most dominant stage in the life-

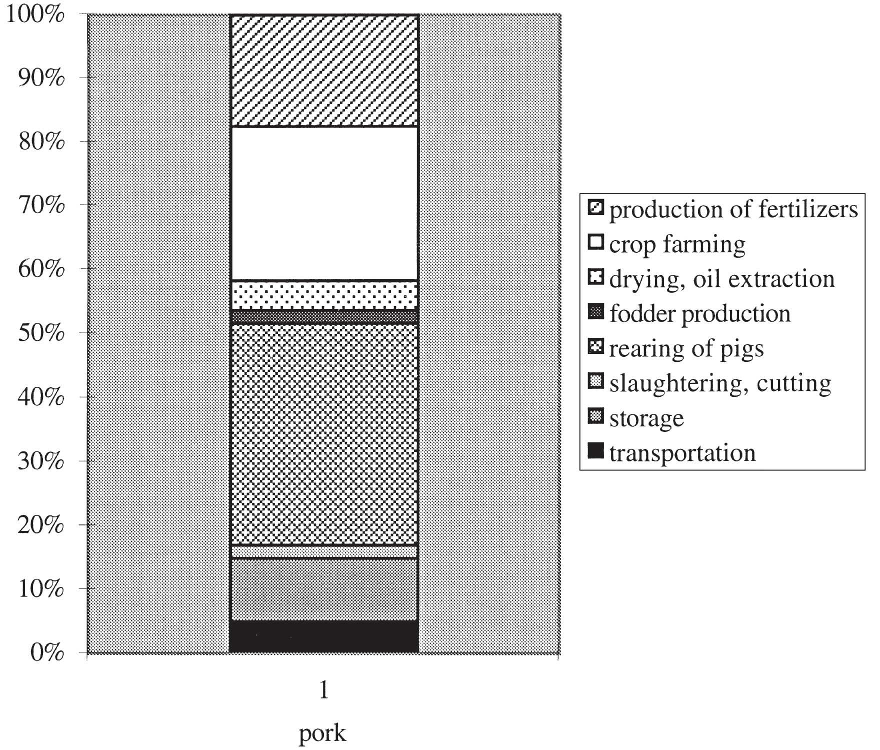

Figure 4 Distribution of greenhouse gas emissions during the life-cycle of pork. In CO_2 equivalents with a 20 year time perspective. All emissions were supposed to occur at the same instant

cycle of pork when the total greenhouse gas emissions were accounted for, was much less significant when energy consumption was the parameter for comparison. Thus, in the energy analysis, rearing of pigs was only 13% of the total while in the greenhouse gas analysis it was 34%. The results from analyses based on the two different environmental parameters were also different for fodder production, drying and oil extraction. These stages were only 7% of the total in the analysis of greenhouse gas emissions, but accounted for 17% of the total energy consumption. The explanation of these differences is that emissions from non-energy related greenhouse gases, such as CH_4 and N_2O, are important in the life-cycle of pork.

The most energy demanding stages in the life-cycle of rice are transportation (47%) while crop farming was much less significant (19%). This can be compared to the analysis of greenhouse gases for rice where transportation only accounted for 6% and crop farming 87%. Again, the explanation for these differences is that the greenhouse gas analysis includes emissions from many more sources than only the energy related ones, in this example mainly CH_4 from irrigated rice fields.

Interpretation of results

The results presented above may be considered as a first attempt to perform a fairly complete estimate of emissions of greenhouse gases during the life-cycle of some foods. Inventory data needs to be improved and expanded. Uncertainties are probably large. The typical uncertainties

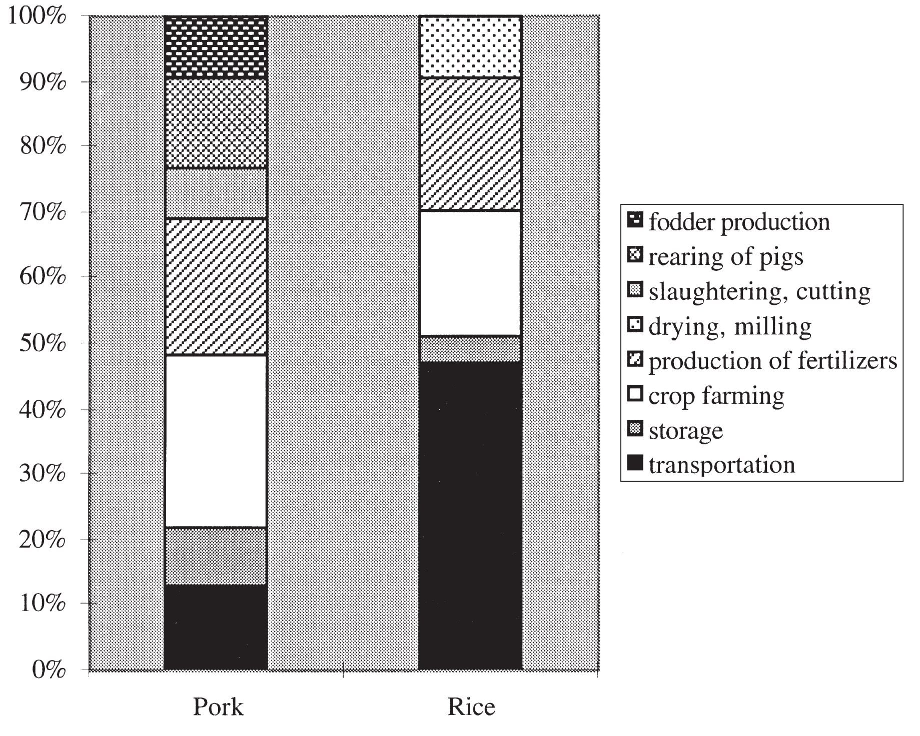

Figure 5 Distribution of energy requirements during the life-cycle of pork and rice

of the Global Warming Potentials only are of the order of ± 35%. The sensitivity of the results to the assumptions made needs to be explored further.

Comparison of greenhouse gas analysis and energy analysis

One of the conclusions that can be drawn from my analysis is that transportation was not a large contributor to the total emissions of greenhouse gases although it often accounted for a major part of the total energy consumption. Furthermore, the analysis of greenhouse gases showed that stages such as storage, pig rearing and rice farming were major contributors, but this was not evident from an energy analysis.

Significant potential impacts caused by emissions of the non-energy related greenhouse gases methane, nitrous oxides, hydrofluorcarbons and fluorcarbons are omitted in conventional energy analysis of food. In view of the fact that these gases are responsible for close to 40% of the direct radiative forcing (calculated from IPCC, 1996a) it seems plausible to conclude that an environmental analysis of food should instead be based on a greenhouse gas emission account rather than an account of energy consumption.

Up until now, however, efforts to improve the environmental performance of food during the life-cycle have mainly been based on energy analysis. This has caused much focus on transportation and little focus on, for example, storage, rearing of animals and cultivation of irrigated rice[3]. Some examples will illustrate how the focus on transportation and energy

[3]One example of a study where transportation has been the main target for environmental improvments is the annual publication by the Swedish Society of Nature Conservation (1996). The title was *Food and the Environment* and in Chapter 3, 'Long road from earth to table', it is written that 'a neighbouring farmer is worth more than half a metre

consumption can sometimes lead to minor improvements only, while a focus on greenhouse gases could bring about more drastic emission cuts.

If energy consumption for transportation is lowered by 30% in the life-cycle of rice, total emissions of greenhouse gases only will decrease by less than 2%. Conventional energy analysis would indicate a decrease in the total emissions connected to the energy consumption by 14% for rice. If energy consumption in the pig house is lowered by 50%, total emissions of greenhouse gases in the life-cycle of pork will decrease by less than 1% while an energy analysis would indicate a decrease of 6%. If emissions of methane during rice farming are lowered by 30%, this would lead to a decrease in the total emissions of greenhouse gases, expressed in CO_2 equivalents, by 23% for rice. The latter measure may prove to be more cost-efficient than lowering energy consumption for transportation. Hence, an analysis with a single numerator such as energy or monetary costs may omit important information for decision-making.

Comparison of analyses using different functional units

The greenhouse gas emissions and energy consumption per kg of food analysed are presented in Table 1. Table 2 shows the nutritional qualities per kg of the same food items as well as a comparison with the results from Table 1 if the functional units used in the analysis were the quantity of energy (MJ/kg), or the contents of protein (g/kg) or vitamin β-carotene (μg/kg) in the food instead of a unit of weight (kg of final product). As can be seen from Table 2, conclusions about the most emitting or lowest emitting food depend entirely on the functional unit chosen.

The most efficient food when only the energy contents are compared is dry peas followed by potatoes and carrots. Tomatoes, with high emissions due to abundant energy requirements during greenhouse cultivation, are highly inefficient as energy suppliers. However, when a different basis of comparison is used — vitamin β-carotene — tomatoes are found to be superior to all other foods analysed, except carrots which are extremely rich in vitamin β-carotene. Since neither rice nor pork contain any vitamin β-carotene, no values of CO_2 equivalents emitted per μg vitamin β-carotene can be calculated. Most efficient for producing protein

Table 2 Nutrient contents of some food (Swedish National Food Administration, 1996) and the emissions of greenhouse gases per unit of nutrient

Food	**MJ per kg**	**Protein (g per kg)**	**β-carotene (μg per kg)**	**g CO_2 equivalents per MJ**	**g CO_2 equivalents per g protein**	**g CO_2 equivalents per μg β-carotene**
Tomatoes	0.83	9	5730	4000	370	1
Carrots	1.67	6	68,000	300	83	0
Potatoes	3.1	18	100	56	10	2
Rice	14.9	68	0	430	94	—
Pork	7.2	180	0	850	34	—
Dry peas	12.4	215	150	55	3	5

of extra insulation on the house', p. 47. Another example of how transportation is targeted is found in a publication from the local environmental protection agency in Stockholm (Agenda 21 Miljöförvaltningen i Stockholm, 1996). In this publication, the energy requirements for transportation of different foods are calculated with the conclusion that locally produced food is more environmentally benign.

with respect to emissions of greenhouse gases are dry peas, followed by potatoes and pork. Thus, by changing the functional unit used for comparing different food items, conclusions about which type of food that is the least or the most environmentally polluting can be quite different.

Characteristics of food with low emissions of greenhouse gases during their life-cycle

Thus, a preferable choice of a functional unit for food may be to use the whole diet or meals with similar nutritional qualities, but even such a comparison is incomplete because the many immaterial qualities of food, such as taste, colour, odour and texture still have to be taken into account.

In Fig. 6, the ingredients of four different meals which contain the same amount of energy and protein, but have very different potentials for changing the global climate, are shown. Fig. 7 shows the emissions of greenhouse gases in g CO_2 equivalents for each of the different meals.

The meals a–d in Fig. 6 can be characterised in the following manner. Meal a is purely vegetarian with ingredients mainly from the domestically produced foods carrots, potatoes and dry peas. Meal b is also vegetarian, but with the exotic ingredients rice and tomatoes in addition to dry peas. Tomatoes are considered exotic because either they have to be imported from southern Europe or else grown in greenhouses. Meal c is solely based on animal and exotic foods: rice, tomatoes and pork while meal d contains only domestically produced food of both animal and vegetable origin. The meals differ with regards to amounts of ingredients also. The ingredients of the vegetarian exotic meal (meal b) weigh only 250 g while the ingredients of

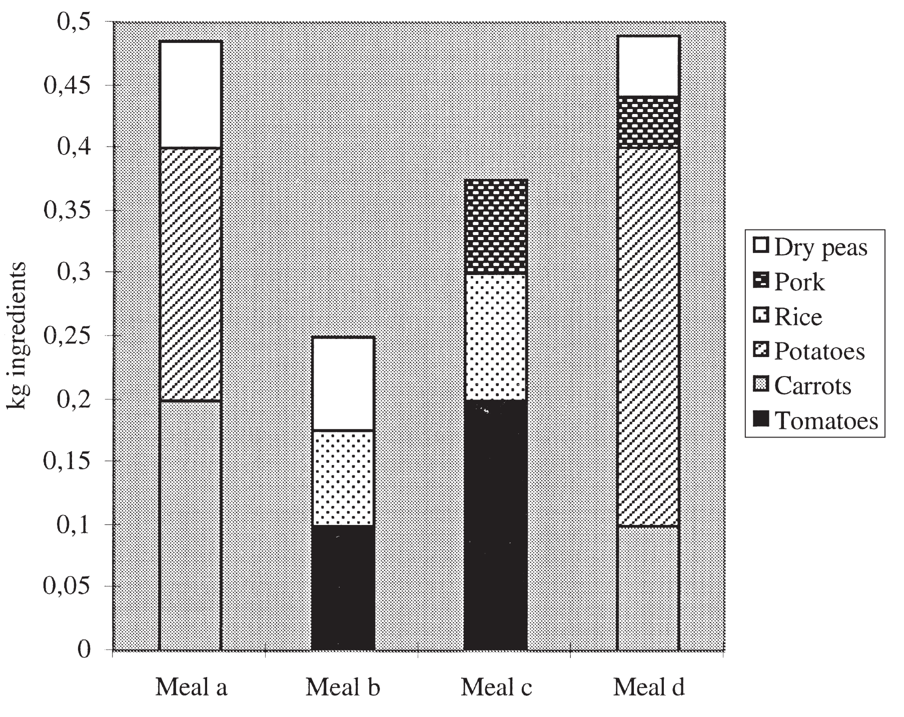

Figure 6 Ingredients of four different meals with the same energy and protein contents (2 MJ and 22–24 g of protein). In kg ingredient per type of food and meal

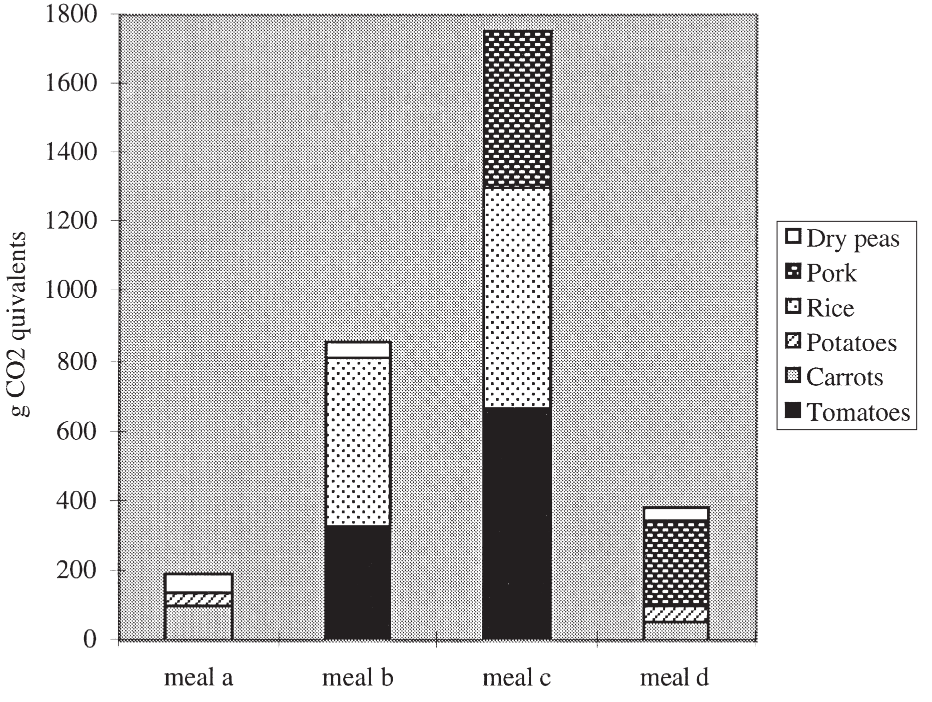

Figure 7 Emissions of greenhouse gases in CO_2 equivalents from four different meals with the same energy and protein contents (2 MJ and 22–24 g of protein). In g CO_2 equivalent with a 20 year time perspective according to meal and type of ingredient

the vegetarian domestic meal (meal a) and the mixed domestic meal (meal d) weigh about 500 grams per meal. These differences influence the magnitude of greenhouse gas emissions from transportation of the ingredients from the retailer to the final consumer, but it has been assumed that these emissions are not large enough to alter the results shown in Fig. 7[4].

In Fig. 7 it is shown that emissions of greenhouse gases during the life-cycle of the four meals differ substantially. The animal–exotic meal (meal c) emits 1800 g of CO_2 equivalents while the vegetarian–domestic meal (meal a) only emits 190 g of CO_2 equivalents. This makes the animal–exotic meal nine times more polluting than the vegetarian–domestic meal. This does not mean that vegetarian food is generally less polluting than animal food. The results in Fig. 7 show that vegetarian food consumption patterns (meal b), may, in some cases, be much more polluting than meals with animal ingredients (meal d). The vegetarian–exotic meal (meal b) emitted 860 g of CO_2 equivalents as compared to only 380 g of CO_2 equivalents for meal d.

[4]For example, assuming that a car consuming 0.9 liters of petrol per 10 km is used for shopping, that the distance to the shop is 5 km and that 30 kg of food is bought. The subsequent emissions of CO_2 may be 91 g of CO_2 per kg of food transported (0.9 liters $\times$ 38 MJ $\times$ 80 g of CO_2 per MJ/30 kg). For the meals a and d that would mean an additional 45 g of CO_2 equivalents, respectively, and for meal b an additional 23 g of CO_2 equivalents.

Current emission levels from food consumption and prospects for sustainability

Sustainable consumption patterns have, for the purpose of the following discussion, been defined according to the following criteria:

- The accumulated emissions of anthropogenic CO_2 from now until 2100 must not exceed a level at which the atmospheric concentration of CO_2 is expected to stabilise at 450 ppmv. This means that accumulated anthropogenic emissions over the period from 1991 to 2100 should not exceed 460 GtC (IPCC, 1996a, Summary for Policymakers).
- Emissions of CH_4 and N_2O should be stabilised at today's levels (1995). This would involve reductions in current anthropogenic emissions of these gases by at least 8% for CH_4 and more than 50% for N_2O (IPCC, 1996a, p. 26). Current anthropogenic emissions of CH_4 have been estimated at 375 Tg per year and the same emissions of N_2O are estimated to be 3–8 Tg N per year (IPCC, 1996a, pp. 18–19).
- Every person now living on the Earth and all those expected to live until 2100 should have the same rights to emit anthropogenic CO_2 and other greenhouse gases. For this purpose, the total number of human years expected to occur from 1991 to 2100 were calculated based on recent population estimates (United Nations, 1995, medium variant of the population projection) and was found to be 977 G human years. Present world population was assumed to be 5.89 G people (United Nations, 1995).

Results from calculations of a sustainable limit for consumption are shown in Table 3 where a total of 5900 kg CO_2 equivalents per capita and year represent the sustainable limit for consumption. This 'greenhouse gas emission space' can be divided into many consumption categories. As a tentative division, let us assume 30% of the greenhouse gas emission space is set aside for common purposes, such as defence, education and health care. Even today, any citizen in any country has to set aside a certain share of his or her monetary income for such purposes. The remaining 70% of the greenhouse gas emissions space, 4100 kg, is supposed to include emissions caused by all other consumption, such as buying and eating food, travelling and heating the home. Assuming that 25% of the remaining space is allocated to food consumption, the sustainable level would be about 1000 kg of CO_2 equivalents per capita and year.

The daily intake of food energy in Sweden has been about 12 MJ per person and day during the last 15 years (Swedish Board of Agriculture, 1997, p. 29). Assuming that all this energy intake is supplied from one of the four different meals presented earlier (meals a–d), the conclusions are as follows.

If all the energy intake during 1 year is supplied by food as in meal a or d, the emissions of greenhouse gases would be 420 and 830 kg of CO_2 equivalents, respectively, which is well within the limits of the estimated greenhouse gas emission space. Meals a and d were both based on vegetable products of the season complemented with pulses and small amounts of pork.

Table 3 The greenhouse gas emissions space for CO_2, CH_4 and N_2O. In kg greenhouse gases and kg CO_2 equivalents per capita and year

Permitted emissions of CO_2 per capita and year 1991–2100	Permitted emissions of CH_4 per capita and year	Permitted emissions of N_2O per capita and year	Permitted emissions of CO_2 equivalents with a 20 year time perspective per capita and year
2400 kg	59 kg	0.67 kg	5900 kg

If, on the other hand, all the energy intake is supplied by food as in meal b or c, the emissions of greenhouse gases would be far above the limit of the greenhouse gas emission space. The emissions from a diet of food as in meal b (vegetarian–exotic) is 1900 kg of CO_2 equivalents per capita and year. For a diet of food as in meal c (animal–exotic) the emissions amount to 3800 kg of CO_2 equivalents. How large the emissions from present Swedish food consumption patterns are in reality remains to be answered, but in view of the fact that animal products contribute to about 30% of the energy supply (Swedish Board of Agriculture, 1997, calculated from p. 31), it seems plausible that present Swedish consumption patterns resemble a diet that causes emissions of the same amount per year as meal c rather than meal a or d. This means that the greenhouse gas emissions from current food consumption patterns exceed the sustainable level by a factor of four.

The prospects for achieving sustainability of such consumption patterns seem questionable. The relationships between standard of living and diet have been reported as predictable and strong with the importance of starchy staples declining as income grows and the importance of ‘luxury food’ increasing (Bender, 1994). In a more prosperous world with an increasing population this seem not to bode well for climate change.

The advocates for more sustainable consumption patterns certainly have many well-founded reasons other than those related to environmental impacts for their claims. For example, a move towards a more vegetable diet in the developed world can be recommended because a substantial amount of grain could then become available for human consumption. This would improve the prospective for supplying a growing world population with an adequate food supply (Kendall and Pimentel, 1994). Also, increased health and obesity problems in the developed parts of the world may be forceful agents for preventing over-consumption. Already such concerns have contributed to changes in the mix of meat consumption towards leaner meats (Bender, 1994). Leaner meat, such as chicken, usually has higher feed conversion efficiencies than red meat, such as beef.

Future food consumption patterns in the developed parts of the world may develop along several different lines. Generally, the demand for convenience food is expected to increase as are concerns for health and the environment (Popcorn, 1991). Meat consumption, and especially the consumption of red meat, may continue to decline because of changing perceptions of the world (Fiddes, 1991). What the consequences in terms of emissions of greenhouse gases will be is unclear. As was shown in this paper, consumption patterns that are purely vegetarian may still be unsustainable. End-use efficiency of food, which is today low, (Bender, 1994) could increase or decrease as a result of the trend for more convenience food.

Conclusions

- Depending on the environmental parameter chosen in an analysis, conclusions about which stage or process to target in the life-cycle of food for pollution control may be quite different. Thus, transportation may be one of the main targets when a conventional energy analysis is used, but not when greenhouse gas emissions from all sources are accounted for. When a conventional energy analysis is used for food, important emissions which affect the climate are not included. This may lead to a sub-optimisation of pollution control.
- Conclusions about sustainable food consumption based on a single functional unit such as weight or energy content of the food itself must be drawn carefully, otherwise recommendations may be skewed. An example of such a misinterpretation is a recent article where

MJ was used as the only functional unit with the result that potato chips, white bread and ice-cream were regarded as more environmentally benign than fruit, high-fibre cereals and meat (New Scientist, 1997, p. 10). This result is not surprising as chips contain 19 MJ per kg (and lots of fat too) as compared to apples which only contain 2.2 MJ per kg (with very little fat but lots of vitamins).

- Food consumption patterns which are low in emissions of greenhouse gases have low shares of animal food and low shares of what, in Sweden, may be considered as exotic ingredients.
- Current Swedish consumption patterns, and most certainly consumption patterns in other parts of the developed world as well, exceed the greenhouse gas emission space with a magnitude of at least a factor of 4. A diet within the limits of the greenhouse gas emission space could, for example, be composed of a small amount of animal products complemented with vegetable protein sources and vegetables of the season. Many of the current trends in food demand seem to be counteracting eventual improvements in technology, such as more fuel efficient lorries, more energy efficient refrigerators and more efficient farming practices. Overall, it seems that technological changes will have to be very profound for reducing current greenhouse gas emissions from food consumption to a sustainable level. Whether those radical changes in food demand that are needed for ecological reasons will occur or not is an open question. Clearly, the future will bring tremendous challenges to every actor connected to food manufacturing, farming or consumption as well as to researchers within all fields.

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