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ANALYSIS

Food and life cycle energy inputs: consequences of diet and ways to increase efficiency

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Abstract

Food consumption is one of the most polluting everyday activities when impacts during product life cycles are considered. Greenhouse gas emissions from the food sector are substantial and need to be lowered to stabilise climate change. Here, we present an inventory of life cycle energy inputs for 150 food items available in Sweden and discuss how energy efficient meals and diets can be composed. Energy inputs in food life cycles vary from 2 to 220 MJ per kg due to a multitude of factors related to animal or vegetable origin, degree of processing, choice of processing and preparation technology and transportation distance. Daily total life cycle energy inputs for diets with a similar dietary energy consumed by one person can vary by a factor of four, from 13 to 51 MJ. Current Swedish food consumption patterns result in life cycle energy inputs ranging from 6900 to 21,000 MJ per person and year. Choice of ingredients and gender differences in food consumption patterns explain the differences. Up to a third of the total energy inputs is related to snacks, sweets and drinks, items with little nutritional value. It is possible to compose a diet compatible with goals for energy efficiency and equal global partition of energy resources. However, such a diet is far from the Swedish average and not in line with current trends.

Keywords: Food; Energy; Life cycle; Consumption; Diet

1. Introduction

Climate change has emerged as perhaps the most urgent global environmental problem and the concentration of greenhouse gases in the atmosphere continues to increase. In an IPCC evaluation from 2001 (IPCC, 2001) it was concluded that the 1990s was the warmest decade since records began, that the consequences of climate change will be more severe than expected

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and that the rate of change is unprecedented during the past 10,000 years. In order to stabilise carbon dioxide in the atmosphere at levels of 450, 650 or 1000 ppmv, global emissions will have to be reduced below the 1990 level within a few decades or within a couple of hundred years and thereafter decrease further and virtually disappear (IPCC, 2001). In Sweden, carbon dioxide emissions increased by 3% between 1990 and 1998 and the prognosis is for a continued increase in the next few years (Klimatkommittén, 2000). Use of fossil fuels is the main contributor to carbon dioxide emissions and changes in energy use patterns will be crucial for successfully stabilising its levels in the atmosphere. The fact that main emissions occur in, or because of, developed countries has led developing countries to abstain from binding commitments to lower their emissions, claiming that essential economic development cannot occur without increased energy use, something that was certainly true for the developed parts of the world (Mwandosya, 2000).

Ultimately, all the environmental impacts caused by man can be related to human consumption patterns. The types and numbers of cars and cattle produced depend both on the number of humans that travel and eat meat and on the frequency with which they do this. Consumption decisions take place in households and the ‘green’ household thus becomes a necessary co-operator as the new societal demand for ecologically rational behaviour grows.

In recent years, a number of studies on the ecological impacts of households have identified food as one of the main contributors to energy use (e.g., Vringer and Blok, 1995; Brower and Leon, 1999) and this is not surprising as the energy use in the food sector commonly amounts to 15–20% of the total in developed countries. Food production and consumption also affect emissions of greenhouse gases through methane emissions from cattle breeding and rice farming and through emissions of N_2O from fertiliser production and application. The intensification of agriculture during recent decades has also altered the biotic interactions and patterns of resource availability in ecosystems (Matson et al., 1997).

Recommendations for lowering energy inputs and greenhouse gas emissions from household food consumption include diets with less meat and cheese, more in-season vegetables and more locally produced and fresh foods (Carlsson-Kanayma, 1998; Kramer et al., 1999; Brower and Leon, 1999; Jungbluth et al., 2000; Faist, 2000; Sundkvist et al., 2001; Pirog et al., 2001). These recommendations are based on studies of life cycle impacts from products and diets, starting with primary production and ending with consumption. The level of detail in the analyses varies from more than 100 food items to just a few, but together they present valuable general guidelines for less-polluting food consumption patterns. Earlier analyses have mostly been too rough to permit actual menu planning, and national differences in the food sector make it difficult to apply analyses made for one country to another. Corrections for differences due to climate and location of producers and consumers are necessary for good national estimates.

In this article we present estimates of life cycle energy inputs for food items, meals and diets relevant for Sweden. They were calculated in the project Urban Households and Consumption Related Resource Use, in which ten households experimented with more energy efficient diets and recorded their food intake in diaries before and after receiving information about desirable dietary changes. The results of this experiment are now being evaluated and will be reported elsewhere. The aim of the present paper is to present and discuss some key results from life cycle energy input calculations carried out on more than 300 food items within the project in order to evaluate household success. This means that the level of detail is such that the results can be used for menu planning and recipe evaluation and also to show how energy inputs for meals with similar nutritional qualities can differ. We present some general guidelines for composing energy efficient meals based on ingredients available on the market and we estimate levels of energy inputs for current and average Swedish food consumption patterns. Lastly, a concept called Climate Watching is discussed. It could stimulate ideas for building an information system with feedback for food consumers against a warmer planet.

2. Methods and materials

2.1. Functional unit, system boundaries and allocation

The inventory of life cycle energy inputs on food items was based on a data survey of energy use in the food sector (Carlsson-Kanyama and Faist, 2000), complemented with additional information from food producers and the literature. The functional unit was one kg of ready to eat food, cooked or non-cooked. We used these results to calculate energy inputs for food portions with portion sizes from SNFA (1999)[1]. The system boundaries in the study included farm production with production of farm inputs, drying of crops, processing, storage and transportation up to the retailer. They also included storage, preparation and cooking in households. The system boundaries excluded production of capital goods such as machinery and buildings, packaging material, waste treatment, transportation from the retailer to the consumer and dishwashing. The economic value of products and by-products was the basis for allocation of energy use during processes with multiple outputs. The energy use was calculated as process energy with no inclusion of production and delivery energy, conversion and transmission losses. Only commercial energy inputs were considered, e.g., inputs derived from electricity, fuel oil, coal or gasoline. Energy inputs from the sun or from human labour were not considered.

2.2. Selection of typical products

In 1997, there were 4200 food variants on the Swedish market compared with the 2700 variants found in retailers of similar sizes in 1976 (Supermarket, 1976–1997). It was beyond the scope of the project to calculate energy inputs for the full range of food variants. A procedure for identifying some products with typical properties was adopted instead (see Fig. 1).

Fig. 1 illustrates a process that started with a survey in several food shops where commonly found variants were recorded with name and address of the producer/importer. Contact with the producers over the phone or by mail followed. Information obtained during contact led to the selection of some typical case products used for the calculation of energy inputs.

Example: A survey in four large food shops owned by different companies revealed that most of the jams displayed were produced in Sweden by a) a large company with a manufacturing plant in the south of Sweden, or b) by smaller producers located in the north of Sweden. Contacts with these producers showed that all sugar used was produced in Southern Sweden or Denmark and that most cultivated fruits were frozen on arrival and came from e.g., Eastern Europe or Central America. Berries harvested in the wild were also frozen on arrival and came from Northern Sweden or Russia. Recipes differed in terms of the proportions of sugar and fruits. Based on these typical properties of jam supplied to Swedish consumers, six typical types were selected for calculations of life cycle energy inputs.

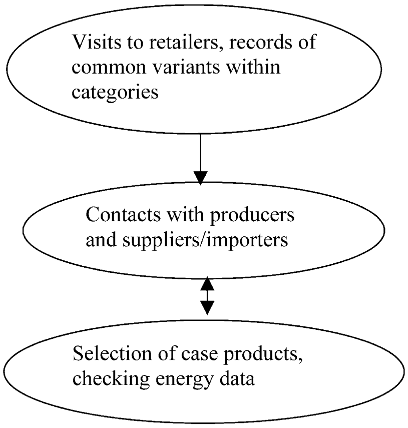

Fig. 1. A procedure for identifying food products with typical properties.

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[1] SNFA (1999) based their estimates on dietary surveys. Therefore, portion sizes of similar food products do not necessarily match each other in terms of nutritional quality but are nevertheless used for menu planning.

2.3. Assumptions

Assumptions about transportation distances, storage times, recipes for products with multiple ingredients (e.g., sausages, sweets, soft drinks) were based on interviews with producers and suppliers of food. Some simplified procedures were then adopted, including estimating energy inputs for transportation, storage and fertiliser manufacture. The same transportation distance was assumed for all products coming to Sweden from continents other than Europe, storage time was assumed to be the same for all deep-frozen products and energy inputs (in MJ per kg fertiliser) for fertiliser manufacture were assumed to be the same regardless of crops cultivated. The assumptions and results are presented in detail in Carlsson-Kanyama (2002).

3. Results

3.1. Levels of energy inputs for food items

Table 1 shows the calculated levels of energy inputs per kg and per portion for 150 food items divided into 19 categories. The selection of products in Table 1 was made so as to fully portray the range of results, with energy input levels varying from 2 to 220 MJ per kg product.

Within the meat category, beef had energy inputs of up to 75 MJ per kg and chicken only 35 MJ per kg, while pork and lamb had 40 and 43 MJ per kg, respectively. This was mainly due to differences in feed conversion efficiencies between species as a result of their rates of basal metabolism (Smil, 2000). However, production systems also count: energy inputs for beef from culled dairy cows decreased to 26 MJ per kg when energy inputs during the cow's life cycle were partitioned between milk, meat and calves, based on their economic value. Within the fish category, the record energy inputs were for shrimps without shells, with a staggering 220 MJ per kg, while clams had inputs of only 19 MJ per kg. Shrimp fishing in the North Sea can require 1.47 kg of fuel per kg of catch and most of this was allocated to the shrimps as they represent almost 100% of the market value. Clams feed on nutrients already present in the ocean and as clam farms are located close to the shore, energy inputs for harvesting remain low. Eggs are another energy efficient animal product with inputs of only 18 MJ per kg. This is due to highly efficient production systems, unfortunately with adverse effects on animal health (Olsson and Keeling, 2000). Cheese has energy inputs similar to certain types of meat and the main reason is the low value of whey, a by-product from the cheese industry. Ten litres of milk are used for one kg of cheese and almost all energy during milk production is allocated to the main product.

Legumes have a high protein content, ranging from 20 to 34% for dried products and in that respect they can be compared with meat and fish. Energy inputs for cooked legume range from 5 to 20 MJ per kg according to our calculations, with the highest value for canned beans from overseas. Legumes are thus often, but not always, an energy efficient alternative to meat and some fish.

Sweets can have large energy inputs, from 18 to 44 MJ per kg (Table 1). In Sweden, consumption of sweets and snacks is equivalent to the amount of fish consumed, about 12 kg per capita and year (Becker, 1999). The increasing consumption of sweets is therefore not only a health concern, but also an ecological issue.

Within the fruit category, there are substantial differences between fruits of different origin. The main difference is transportation energy use, a function of distance and vehicle efficiency. Distance explains why apples from overseas require 8.6 MJ per kg while apples from Sweden only require 3.5 MJ per kg, despite the fact that apples from overseas come by energy efficient ships. Vehicle efficiency (or rather inefficiency) explains why fresh tropical fruits from overseas transported by plane have record energy inputs of 115 MJ per kg. Fresh fruits and berries may be transported by plane if very perishable.

There are important differences between vegetables grown in the open. Energy inputs of 20 MJ per kg were found for the edible parts of frozen and imported broccoli, partly due to the low utilisation rate of the product, only 60%. This can be contrasted to the levels found for canned

Table 1
Life cycle energy inputs for foods ready to eat

Category	Food type, origin and preparation	MJ life cycle inputs per kg	kg per portion	MJ per portion
Lamb	Lamb, fresh, Sweden, cooked	43	0.125	5.4
	Lamb, frozen, Sweden, cooked	46	0.125	5.7
	Lamb, frozen, overseas, cooked	52	0.125	6.5
	Sausage, fresh, Sweden, cooked	30	0.125	3.8
	Lamb stew, Sweden, cooked	18	0.25	4.5
Chicken	Chicken, fresh, Sweden, cooked	35	0.125	4.4
	Chicken, frozen, Sweden, cooked	39	0.125	4.8
	Chicken, frozen, Central Europe, cooked	41	0.125	5.1
	Sausage, fresh, Sweden, cooked	20	0.125	2.5
	Chicken stew, cooked	13	0.25	3.4
Pork	Pork, fresh, Sweden, cooked	40	0.125	5.0
	Pork, Sweden, frozen, cooked	43	0.125	5.3
	Pork, frozen, Central Europe, cooked	44	0.13	5.5
	Sausage, fresh, Sweden, cooked	34	0.13	4.2
	Pork stew, cooked	17	0.25	3.9
Beef	Beef, fresh, Sweden, cooked	70	0.13	8.8
	Beef, frozen, Central Europe, cooked	75	0.13	9.4
	Cow, fresh, Sweden, cooked	26	0.13	3.2
	Beef stew, cooked	24	0.25	6.1
Fish and crustaceans	Cod, fresh, Sweden, cooked	105	0.13	13
	Herring, fresh, Sweden, cooked	22	0.125	2.8
	Mackerel, fresh, Sweden, cooked	37	0.125	4.7
	Canned tuna, overseas	44	0.125	5.6
	Salmon, farmed, Sweden, cooked	84	0.125	11
	Clams, tinned, Sweden	19	0.125	2.3
	Shrimps, without shells, Sweden	220	0.125	27
Milk, cheese	Milk, Sweden, 4% fat	5.9	0.2	1.2
	Milk, Sweden, 1.,5% fat	5.0	0.2	1.0
	Cream, Sweden, 40% fat	19	0.025	0.5
	Yoghurt, small pots, Sweden	11	0.2	2.2
	Yoghurt, small pots, Central Europe	12	0.2	2.5
	Cheese, Sweden	60	0.015	0.9
	Cheese, Central Europe	64	0.015	1.0
	Cheese, Southern Europe	65	0.015	1.0
	Milk powder, Sweden	58	0.008	0.5
Egg	Eggs, Sweden, cooked	18	0.1	1.8
Legumes	Brown beans, Sweden, cooked	8.9	0.19	1.70
	Yellow peas, Sweden, cooked	5.0	0.19	0.95
	Soya beans, overseas, cooked	7.9	0.19	1.51
	Brown beans, overseas, cooked	11	0.19	2.11
	Beans, canned, overseas	20	0.19	3.71
	Beans, canned, overseas	16	0.19	3.09
Sugar and candies	Sugar, Sweden	9.8	0.0035	0.03
	Honey, Sweden	1.3	0.0035	0.004
	Honey, overseas	5.6	0.0035	0.02
	Candies, Sweden	18	0.1	1.8
	Chocolate, Central Europe	44	0.1	4.4
	Chocolate, Sweden	43	0.1	4.3
	Ice-cream, Central Europe	15	0.1	1.5
	Ice-cream, Sweden	14	0.1	1.4
Oil and fat	Rape seed oil, Central Europe	15	0.014	0.21

Table 1 (*Continued*)

Category	Food type, origin and preparation	MJ life cycle inputs per kg	kg per portion	MJ per portion
	Sun flower oil, overseas	20	0.014	0.28
	Soya oil, overseas	14	0.014	0.19
	Olive oil, Southern Europe	24	0.014	0.33
	Butter, Sweden	40	0.014	0.56
	Margarine, Sweden, 80% fat	17	0.014	0.23
Fruits	Apples, fresh, Sweden	3.5	0.125	0.44
	Apples, fresh, Central Europe	4.8	0.125	0.60
	Apples, fresh, overseas	8.6	0.125	1.1
	Cherries, fresh, Sweden	5.0	0.125	0.63
	Cherries fresh, Central Europe	6.2	0.125	0.78
	Cherries, fresh, overseas	9.6	0.125	1.2
	Apples, dried with commercial energy, overseas	38	0.025	0.95
	Apples, dried in the sun, overseas	18	0.025	0.44
	Oranges, fresh, Southern Europe	6.8	0.11	0.75
	Oranges, fresh, overseas	9.4	0.11	1.0
	Grapes, fresh, Southern Europe	7.8	0.125	0.97
	Grapes, fresh, overseas	9.7	0.125	1.2
	Raisins, dried in the sun, overseas	23	0.045	1.0
	Bananas, fresh, overseas	12	0.105	1.3
	Tropical fruit, canned, overseas	13	0.115	1.5
	Tropical fruit, fresh, overseas by plane	115	0.125	14
Vegetables	Potatoes, Sweden, cooked	4.6	0.2	0.91
	Potatoes, Sweden, baked	29	0.2	5.7
	Potatoes mashed powder, Sweden, cooked	5.6	0.2	1.1
	French fries, Sweden, cooked as one portion	60	0.125	7.6
	French fries, Sweden, cooked as four portions	30	0.125	3.7
	Carrots, fresh, Sweden	2.7	0.07	0.19
	Carrots, fresh, Central Europe	4.0	0.07	0.28
	White cabbage, Sweden	3.7	0.07	0.26
	White cabbage, Central Europe	5.1	0.07	0.35
	Broccoli, frozen, Europe, cooked	18	0.07	1.2
	Broccoli, frozen, overseas, cooked	20	0.07	1.4
	Carrots, canned, Sweden	8.1	0.07	0.56
	Carrots, canned, Central Europe	11	0.07	0.74
	Tomatoes, canned, Southern Europe	14	0.07	1.0
	Olives, canned, Southern Europe	15	0.07	1.1
	Vegetables, canned, overseas	18	0.07	1.3
	Peas, frozen, Sweden, cooked	10	0.07	0.72
	Peas, frozen, Central Europe, cooked	12	0.07	0.84
	Tomatoes, fresh, greenhouse, Sweden	66	0.07	4.6
	Tomato, fresh, Southern Europe	5.4	0.07	0.37
Jam	Wild berry jam, factory in South Sweden, 55% fruit	11	0.02	0.22
	Wild berry jam, factory in South Sweden, 45% fruit	11	0.02	0.23
	Raspberry jam, factory in Northern Sweden, 55% fruit	16	0.02	0.33
	Raspberry jam, factory in Northern. Sweden in, 45% fruit	16	0.02	0.32
Breakfast Cereals	Müsli with sun dried apples, Sweden	15	0.04	0.615
	Müsli with sun dried raisins, Sweden	17	0.04	0.686
	Oat flakes, Sweden	11	0.04	0.46
	Oat flake porridge Sweden, cooked	2.5	0.275	0.69
	Baked cereal, Sweden	37	0.04	1.473
	Baked cereal, Central Europe	38	0.04	1.528
Berries	Raspberries, frozen, Central Europe	16	0.125	2.0

Table 1 (*Continued*)

Category	Food type, origin and preparation	MJ life cycle inputs per kg	kg per portion	MJ per portion
	Raspberries, fresh, Central Europe	7.5	0.125	0.9
	Blueberries, frozen, Central Europe	9.0	0.125	1.1
	Blueberries, frozen, Sweden	7.8	0.125	0.98
	Strawberries, fresh, Sweden	6.2	0.125	0.77
	Strawberries, fresh, Southern Europe	8.6	0.125	1.1
	Strawberries, fresh, Middle East, by plane	29	0.125	3.6
	Strawberries, frozen, Central Europe	16	0.125	2.0
Cereals	Whole wheat Sweden, cooked as one portion	4.4	0.12	0.52
	Whole wheat Sweden, cooked as four portions	2.9	0.12	0.34
	Rice, overseas, cooked as one portion	7.4	0.18	1.3
	Rice, overseas, cooked as four portions	6.1	0.18	1.1
	Pasta, Sweden, cooked	6.8	0.175	1.2
	Pasta, Southern Europe, cooked	7.5	0.175	1.3
	Fresh pasta, Sweden, cooked	8.9	0.213	1.9
	Barley, Sweden, cooked	2.0	0.188	0.38
	Couscous, Central Europe, cooked on a hot plate	5.3	0.2	1.1
	Couscous, Central Europe, cooked with a kettle	5.1	0.2	1.0
	Rye flour, Sweden	5.2	–	–
	Wheat flour, Sweden	5.0	–	–
Bread and Pastries	Bread, fresh, local bakery	8.9	0.05	0.44
	Bread, frozen, local bakery,	12	0.05	0.58
	Bread, fresh, bakery far away	9.7	0.05	0.48
	Bread, frozen, bakery far away	13	0.05	0.63
	Crispbread, Sweden	14	0.025	0.36
	Sponge cake, Sweden, with butter	16	0.05	0.78
	Sponge cake, Central Europe, with butter	19	0.05	0.91
	Sweet bread, Sweden with butter	19	0.06	1.13
	Sweet bread, Central Europe, with butter	21	0.06	1.28
	Sweet bread, Sweden, with margarine	15	0.06	0.90
	Sweet bread, Central Europe, with margarine	18	0.06	1.05
	Biscuits, Sweden, with butter	23	0.03	0.70
	Biscuits, Central Europe, with butter	26	0.03	0.77
	Cream cake, Sweden	16	0.10	1.6
	Apple cake, Sweden, with butter	18	0.10	1.8
	Apple cake, Sweden, with margarine	14	0.10	1.4
Drinks	Soft Drinks, Sweden	5.9	0.2	1.17
	Soft drinks, Central Europe	7.1	0.2	1.42
	Wine, Southern Europe	12	0.2	2.42
	Wine, overseas	14	0.2	2.77
	Beer, Sweden	12	0.2	3.00
	Water from tap	< 0.0	0.2	0.0
	Water from bottle, Central Europe	2	0.2	0.40
	Orange juice, overseas	10	0.2	2.01
	Apple juice, Central Europe	7.1	0.2	1.42
Spices	Herbal spice, Southern Europe, commercially dried	36	–	–
	Herbal spice, Southern Europe, sun dried	16	–	–
	Herbal spice, overseas, sun dried	23	–	–

vegetables, which varied from 8 to 18 MJ per kg. Thus, fresh products are not always more energy efficient than processed. The 'old' truth of vegetables grown in greenhouses, being energy demanding was confirmed in this study, with energy inputs for tomatoes calculated to 66 MJ per kg. However, when French fries were cooked as one portion in an oven, energy inputs per kg became almost equally high and most of those energy inputs relate to heating the electric oven.

In general, pastries with butter are more energy demanding than pastries baked with margarine, as butter had energy inputs of 40 MJ per kg while margarine had less than half of that. Margarine is made from vegetable oils while butter is made from cream, a product of animal origin. Typical pastries have energy inputs ranging from 16 to 26 MJ per kg and that puts them at the same level as certain protein rich products such as eggs and herring. Drinks range from less than 1 MJ per kg (water from the tap) up to 14 MJ per kg (wine from overseas) and considering that just one glass may contain 0.2 kg of liquid, it is easy to appreciate that drinks may contribute significantly to the energy total of a diet.

A somewhat different pattern than that described above emerges when the life cycle energy inputs per portion of food are compared instead of the inputs per kg, Sun-dried fruits appear as a very energy efficient alternative with only 0.44 MJ per portion, a level comparable with one portion of domestic fresh apples. In contrast, dried fruits require 18 MJ per kg compared with 3.5 MJ for one kg of fresh apples. Dried products weigh less than fresh, do not need refrigerated storage and a portion is small because nutrients are concentrated.

In diet formulation, the whole food consumption pattern is important and exchanging one product for another cannot be considered in isolation. In the next section, we use the results in Table 1 to estimate energy inputs for meals and diets that provide an adult with acceptable nutrition.

3.2. *Examples of meals with high and low life cycle energy inputs*

As shown, food products with similar functions and nutritional qualities can differ widely in terms of life cycle energy inputs, so meals and diets can be more or less energy efficient while providing households with adequate nutrition. Table 2 shows the meal components and energy inputs for two dinners that have similar amounts of dietary energy, about 2.5 MJ, but differ in life cycle energy inputs by a factor of three, from 6 to 19 MJ.

Meal High in Table 2 differs from Meal Low by the ingredients chosen and by amounts of ingredients used. For example 0.13 kg of beef is used in Meal High, and as this ingredient requires 75 MJ inputs of life cycle energy per kg, the resulting energy input to the dinner is 9.4 MJ. In Meal Low, the same amount of meat is used but it comes from chicken, and total energy inputs for it are only 4.4 MJ. The other main differences between the two dinners are the types and amounts of vegetables and drinks included. By choosing those vegetables grown in the open, it is possible to include large amounts while keeping energy inputs moderate. Wine is made of grapes, an intensively cultivated crop, and every litre of wine requires 1.5 kg of grapes, while transportation from overseas adds to energy inputs. Tap water is produced with very low energy inputs in Sweden as surface or ground water is available nearby.

In a similar manner, we composed two lunches with energy inputs ranging from 3.1 to 14 MJ (not in table). The energy efficient meal included legumes, whole wheat, tubers and leeks, while the energy demanding meal included French-Fries, pork, frozen broccoli and canned pineapples. Differences between the two meals are mainly explained by the choices of highly processed products over non-processed ones and by the choice of pork versus legumes. The latter choice is highly conducive to energy efficiency but may be difficult to implement in Sweden due to the fact that Swedes have no strong tradition of legume consumption, unlike many Asian or African countries (Carlsson-Kanyama and Lindén, 2001).

The life cycle energy inputs for two breakfasts with similar dietary energy were 3.0 and 6.8 MJ

Table 2
Meal components, dietary energy and life cycle energy inputs for two different dinners, high and low

Meal component	Kg	MJ dietary energy (SNFA, 1996)	MJ life cycle inputs
Dinner: high			
Beef	0.13	0.80	9.4
Rice	0.15	0.68	1.1
Tomatoes, greenhouse	0.070	0.06	4.6
Wine	0.30	0.98	4.2
Total	0.65	2.51	19
Dinner: low			
Chicken	0.13	0.81	4.37
Potatoes	0.20	0.61	0.91
Carrot	0.13	0.21	0.50
Water, tap	0.15	0.23	0.0
Oil	0.02	0.74	0.30
Total	0.60	2.61	6.1

(Table 3) and differed by a factor of two. The differences are partly explained by choices of vegetable products over animal but mainly by choices of more/less processed and transported products and of products produced in the wild (lingonberries) over cultivated (raspberries).

To complete the account of differing energy inputs for daily food consumption, we propose two snacks: 0.10 kg of fresh tropical fruit flown in from overseas, resulting in 11 MJ energy inputs, or a domestically produced apple, resulting in 0.44 MJ energy inputs, thus a difference by a factor of 25. Air transport is very energy demanding while energy inputs in the life cycle of a fresh apple are comparatively low, as there are no processing costs and shorter transportation distances.

Based on these meals, total daily life cycle energy inputs for food consumed by one person vary from 13 MJ to four times that, 51 MJ (Fig. 2), but both examples represent diets with adequate

Table 3
Meal components, dietary energy and life cycle energy inputs for two different breakfasts, high and low

Meal component	kg	MJ dietary energy (SNFA, 1996)	MJ life cycle inputs
Breakfast: high			
Yoghurt, imported	0.15	0.59	1.8
Baked cereal product	0.04	0.64	1.6
Raspberry jam	0.02	0.15	0.32
Bread, frozen, imported	0.07	0.76	0.88
Cheese	0.03	0.46	1.8
Butter	0.01	0.30	0.40
Total	0.32	2.9	6.8
Breakfast: low			
Milk	0.15	0.36	0.74
Oat porridge	0.23	0.50	0.57
Lingonberry jam	0.02	0.13	0.22
Apple, Sweden	0.05	0.11	0.17
Bread, fresh, local bakery	0.07	0.76	0.62
Egg	0.03	0.18	0.53
Margarine	0.01	0.30	0.17
Total	0.56	2.3	3.0

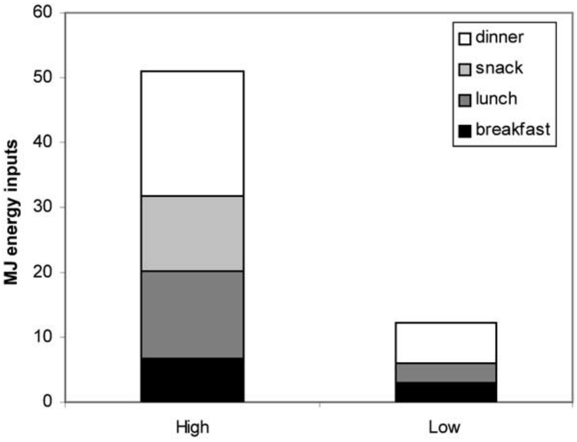

Fig. 2. Examples of life cycle energy inputs for two daily diets for one person. The two diets have similar amounts of diet energy but the High differs from the Low by a factor of four in terms of life cycle energy inputs.

dietary energy, about 7.8 MJ. This is the level of daily dietary energy intake reported by Swedish women (Becker, 1999). Both diets are also based on ingredients commonly available on the Swedish market. The cost for the Diet Low is most probably lower than the cost for the Diet High.

Energy inputs for theoretical diets need to be compared with those for present consumption patterns in order to estimate deviance. In the next section we calculate possible energy input levels for today's average food consumption in Sweden.

3.3. *Levels of life cycle energy inputs for current food consumption patterns*

Data on food consumption were obtained from a survey conducted in 1997/1998 by the National Food Administration in Sweden. The survey covered 1215 households that recorded their food intake during one week. The average daily food intake for men and women is reported in 34 categories (Becker, 1999) such as 'butter and margarine', 'meat and fowl' or 'fish and crustaceans'.

Based on these data, the total annual food consumption for the two sexes was estimated to be 1040 kg for women and 1080 kg for men, including all drinks (even tap water). When drinks such as water, coffee and tea were excluded, the total annual consumption was 590 kg for women and 730 kg for men. Men and women differ as regards the total amount of food eaten, but men also eat 63 kg of meat and meat products per year while women eat 47 kg. Women, on the other hand, eat 100 kg of fruit and vegetables per year while men eat 73 kg.

Assuming the sexes made different choices in each food category, energy inputs for women's annual food consumption varied from 6900 to 18 000 MJ and for men's from 8300 to 21,000 MJ. An example of an assumption that contributed to the differences was the choice of shrimps with 220 MJ per kg versus herring with 22 MJ per kg when the category 'fish and crustaceans' was computed. Differences due to gender affect levels of energy inputs for food consumption. Assuming that both men and women make the same food choices within a category, energy inputs are 14 to 21% higher for men (Fig. 3).

The levels shown in Fig. 3 can be interpreted as maximum and minimum levels of per capita life cycle energy inputs for present eating patterns in Sweden.

4. Discussion

4.1. *Comparisons with earlier studies*

It is complicated to compare the absolute levels of energy inputs per kg of product calculated in our study with others because of differences in system boundaries, allocation and energy accounting methods, etc. It is not so common to include the consumption phase and its losses as we did, allocation is sometimes based on principles other than economic and accounting for primary energy gives higher figures than when process energy only is calculated. Nevertheless, a few studies are available for comparison. In a Swedish study of bread that included the consumption phase as well as agriculture, processing, packaging and waste management (but not consumer losses), Andersson and Ohlsson (1999) found primary energy inputs for bread ranging from 12 to 22 MJ per kg. The study was made using life cycle assessment (LCA)

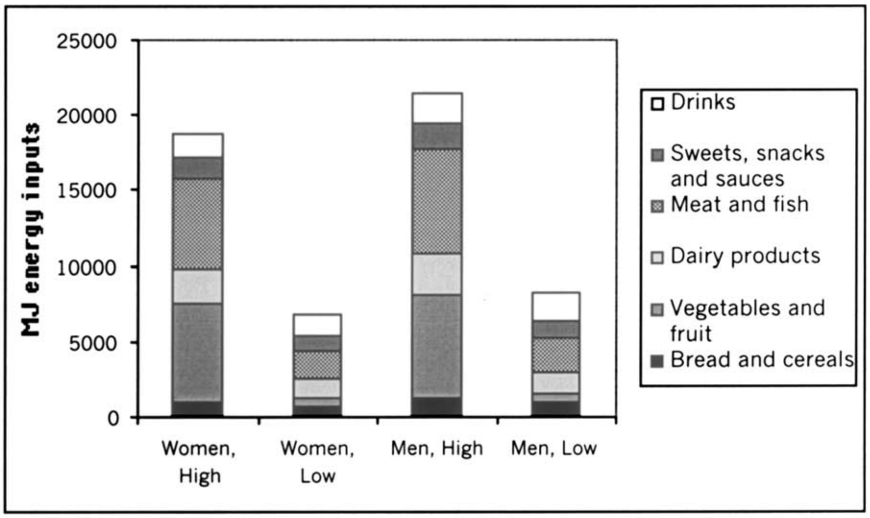

Fig. 3. Life cycle energy inputs for the annual food consumption of average men and women in Sweden. The ranges indicate possible levels with different food choices within each category.

methodology. In our study, bread had life cycle energy inputs of 9-13 MJ. Mattsson (1999) calculated the LCA energy inputs for carrot puree sold in glass jars of 135 grams and included agriculture, processing, packaging, distribution and consumption. She found primary energy inputs of about 23 MJ per kg. That may be compared with the energy inputs for raspberry jam in our study of 16 MJ per kg. In the study by Mattsson (1999) packaging accounted for 6 MJ per kg, while in our study packaging was excluded. In an LCA of conventional milk production up to the farm gate, Cederberg and Mattsson (2000) found primary energy inputs of 3.5 MJ per kg. This can be compared with the 5.9 MJ per kg in our study for milk with 4% fat content. The higher inputs in our study are explained by processing, transport and storage after the farm gate, as well as losses during these stages. In a study of cod where the functional unit was a frozen block, the primary energy use became 95 MJ per kg and fishing, which uses large amounts of fuel, was the dominant contributor (Ziegler et al., 2002). We calculated process energy for ready-to-eat cod of 105 MJ per kg and the higher value is explained by losses during preparation and consumption as well as energy for cooking. In summary, we found that our levels of energy inputs per kg of product seem plausible when compared with results obtained by others using a similar approach.

We also compared the calculated energy input levels for the national diets displayed in Fig. 3 and ranging from 6900 to 21,000 MJ with the levels resulting from our High/Low diets (Fig. 2) if the latter were consumed every day of the year. The annual energy inputs for one person consuming Diet Low daily become 4600 MJ and for Diet High 19,000 MJ, results roughly in line with the national estimates (Fig. 3). Diet Low is quite energy efficient and it is an extreme variant of today's food intake but could apply to the food patterns of an older generation accustomed to herring, small amounts of meat and a lot of tubers (Carlsson-Kanyama and Lindén, 2001). The possibilities of comparing our annual food energy input levels with results from other studies relevant for Sweden are few. One study showed approximate energy inputs to the whole food sector excluding transport from retailers to homes and packaging of 30 TWh per year (Naturvårdsverket, 1997). Divided by a population of NINE million inhabitants, energy inputs per capita become 12,000 MJ according to this estimate. There are several differences in system boundaries between our study and that by Naturvårdsverket (1997). The latter does not include agriculture and processing abroad and since Sweden is a net importer of food, the calculated energy levels must be an underestimate.

4.2. Uncertainties

Major uncertainties when calculating the life cycle energy inputs of food on a per item basis are related to waste levels, especially during the consumption phase because such assumptions have a high impact on total energy inputs. If one resource unit is used to produce one kg of edible food and if half the food is thrown away, then two resource units are needed for every kg food ingested. Bender (1994), Smil (2000) propose lower waste levels as one of the most important measures for lowering global food demand. Measurements of food waste at table are few, but a recent study carried out in Sweden found that around 10% of the food on the plate was wasted (Karlsson, 2001). Better estimates of food waste in the stages of the life cycle close to the consumer are necessary for further improving the quality of results.

A choice in any energy analysis is whether or not to include conversion losses in the calculations. It is electricity use that will be most sensitive to that choice, as power production may have as low conversion rate as 25–30% or as high as almost 100% (hydropower). We chose not to include conversion efficiency in this study, something that mostly affects results for products that are refrigerated or cooked for a long time. Cooking in Sweden is mostly carried out on electrical stoves and refrigeration depends on electricity. Further analyses of our material could include a sensitivity analysis of excluding the conversion losses as well as an analysis of how results depend upon the magnitude of conversion losses assumed.

Food packaging was excluded in our study but is commonly included in other life cycle assessments of food. Its contribution to the total energy input profile is a function of package weight related to food weight and type of packaging material. Most foods bought in Sweden are packaged in several different sizes and packaging material can vary for the same product. Thus, jam can be bought in glass jars or plastic containers of several different sizes. When analysing jam in general, ideally all packaging options should be included. This will require substantive data collection but would certainly highlight the role of packaging in the environmental life cycles of food.

4.3. New knowledge with respect to environmental dietary guidelines

Our results confirmed several recommendations and conclusions made in earlier studies but they also added new knowledge about the energy efficiency of food consumption patterns. For example, while the general conclusions that meat and vegetables grown in greenhouses are more energy demanding than many vegetables grown in the open (Carlsson-Kanayma, 1998; Kramer et al., 1999) still have relevance, it is important also to look at the meat type before recommending vegetables over meat products. For example, sausages from chicken meat had energy inputs of 20 MJ per kg and that is equal to frozen broccoli from overseas. The low-energy input level for chicken sausages is explained by both the high feed conversion rate of broilers as well as the composition of sausages, which contain about 60% meat while the rest of the ingredients are of vegetable origin. Another lesson from our study is that very energy efficient fish products may be identified, such as herring and clams with about 20 MJ per kg, while very high-energy inputs may be needed for products such as shrimps. Life cycle energy inputs for fish products seem to vary more than for any other product group (Carlsson-Kanyama, 2002). Therefore, recommendations for more energy efficient product choices have to consider that animal products have different energy profiles.

Sweets, snacks and drinks are seldom studied in detail for their environmental impact. However, the results of energy inputs for diets (Fig. 3) show that these products may well contribute to up to a third of total energy inputs for food consumption. The consumption of such products should therefore be of interest in the debate about more sustainable consumption patterns and not only, as is now, when debating the adverse health impacts of food intake. It would also be interesting to expand such a discussion to include the functional role of sweets and to look for more energy efficient and non-consumption alternatives? If eating sweets means comfort, perhaps an energy efficient back-rub could do the trick?

4.4. Energy inputs for diets compatible with long-term goals for stabilising climate change

We can ask to what extent current levels of energy inputs related to food consumption, whether high or low, are compatible with long-term goals for stabilising climate change. Emissions of greenhouse gases could be sharply reduced if energy systems were based on renewable energy instead of fossil fuel. The global potential for renewable energy supply was estimated at 360 EJ per year by Steen et al. (1997), who calculated it with respect to areal limits and material constraints. This figure can be compared with the World's primary energy consumption in 1998, 400 EJ (Goldemberg et al., 2000).

Here, we adopted the 400 EJ level as a basis for assessing whether our energy-input levels for food consumption were compatible with long-term environmental goals on more efficient energy use. Thus we assumed that current energy consumption levels must not be exceeded. We also assumed an equitable partition of the energy consumed, leaving each of the six billion people on Earth with 67,000 MJ per year. If 20 of the 70% post-tax per capita energy consumption are set aside for food consumption, every citizen can use 9000 MJ per year for his or her diet. These 9000 MJ should include all life cycle energy inputs and the level is therefore comparable with our examples from diets with high- and low-energy inputs (Figs. 2 and 3).

The annual per capita life cycle inputs for present food consumption showed possible variations from 6900 MJ up to 21,000 MJ per year (Fig. 3). Clearly, it is already possible at present to compose a diet with energy inputs compatible with energy efficiency goals while respecting demands from developing countries to increase their energy use for economic development. However, current trends towards more animal and exotic food may not be conducive to further reductions in dietary life cycle energy inputs (Carlsson-Kanyama and Lindén, 2001).

4.5. Climate watchers- a concept for food consumers against global warming?

It is well known that information without feedback has little effect on consumer behaviour. However, information and feedback about the consequences of actual behavioural changes can have effects on behaviour and consumption patterns (Dwywe et al., 1993). This leads to the idea of creating an information system that would enable consumers to monitor their energy input levels from food consumption and to compare them with goals for energy efficiency.

Any concept involving consumers in a large-scale experiment on more energy efficient diets certainly needs careful consideration and elaboration beyond the scope of this article. Perhaps methods already used in dieting programmes such as Weight Watchers could inspire? In Sweden there are at least 1000 self-help groups adhering to the Weight Watchers programme, where about 30 people meet every week to receive feedback in terms of recorded weight loss, and to receive recommendations from a trained instructor about product choices and how to overcome temptation. Group members are given information about how many energy and fat-based ‘points’ an ingredient or meal contains and are recommended a maximum points level per week based on age, gender and weight (Weight Watchers, 2001).

We can envisage a weekly meeting of Climate Watchers, where the participants bring their food diaries or receipts and receive feedback in terms of life cycle energy inputs. The results would be compared with a weekly upper level, perhaps based on similar principles to our calculation of energy inputs compatible with long-term goals for stabilising climate change (Section 4.4). From our examples of energy inputs for foods and meals, it is clear that energy efficient diets could be achieved by adopting a multitude of different strategies. Some of them have already been explored but most will probably be discovered among the opportunities and constraints of everyday life.

However, even if such a programme were to be established, consumers cannot be expected to act on information alone. Numerous other measures have to be taken and will probably include food taxation, regulations, morals and structures, which are currently making a more energy efficient consumption pattern difficult.

5. Conclusions

- Energy inputs in the life cycles of food items can vary from 2 to 220 MJ per kg due to a multitude of factors related to animal or vegetable origin, degree of processing, choice of processing and preparation technology and transportation distance. Comparisons of life cycle energy inputs for food should preferably be made per meal with similar nutrient contents.
- Within the animal product category, life cycle energy inputs for a portion can vary from 1.8 to 7.7 MJ. Thus, guidelines for lowering consumption of animal products should identify energy efficient animal alternatives.
- The total life cycle energy inputs for food per person and day can vary from 13 to 51 MJ. The example given is for diets with a similar nutritional content and both are based on ingredients commonly available on the Swedish market.
- Current Swedish food consumption patterns may result in life cycle energy inputs ranging from 6900 to 21,000 MJ per person and year. Gender differences in food consumption patterns and choice of ingredients explain the differences.
- Energy inputs for sweets, snacks and drinks may account for up to a third of the total for food. Increased attention should be given to the environmental consequences of such items in a diet.
- It is possible to compose a diet compatible with goals for energy efficiency and equal global partition of energy resources; however, such a diet is far from the Swedish average and not in line with current trends.

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