

Energy Consumption in the Food Chain

Comparing alternative options in food production and consumption

Energy consumption in the various stages of the food chain, provides a reasonable indicator for the environmental impact in the production of food. This paper provides specific information on the energy requirement for the main alternatives in each production stage, which should allow the identification of improvement options. One observation is that there seems to be a remarkable relationship between energy requirement throughout the production chain and market value. Products with a high added (emotional) value, e.g. wine, season fruits, and coffee, deviate from the abovementioned relationship. However, that deviation may be overcome when the emotional value is included in the functional unit of the food product. It is concluded that there seems to be no systematic environmental benefit for home-made over industrially produced food. For all food categories, there is a wide variety in energy requirement due to three major factors, viz. season of consumption (fresh versus import and glass-house production), scale of preparation (home-made and industrial scale) and consumer preference (meat versus vegetable food).

INTRODUCTION

Food production contributes directly or indirectly to environmental impacts in various parts of the world. Individuals consume on average between 200 and 300 kg food per year (drinks ex-

cluded), irrespective of what part of the world they come from (Kusin, J.A., Royal Tropical Institute, Amsterdam, pers. comm.). There is, however, a profound difference in the environmental impact between the various meals. The use of energy can act as an indicator for environmental impact in the production of food, as many environmental problems, like climate change, acidification potential and depletion of non-renewable resources, are related to energy consumption (1). Reduction of energy use is a major issue (2). Other studies have shown that the consumption of food has a 20–35% share in the total energy use of a household (3, 4). This article discusses the energy use of food products, in order to highlight the major causes for energy consumption, and to identify options for improvement. Nonenergy related environmental impacts that are particularly relevant for food include eutrophication, greenhouse effect, and toxicity (including both human toxicity and ecotoxicity) due to the use of fertilizers and pesticides in agriculture. These impacts are not considered in this study.

METHODS AND ASSUMPTIONS

For a complete view of the energy use of food products the entire life cycle has to be taken into account. Several studies provide data about the energy use of food products (5, 6). The approach of Life Cycle Assessment (LCA) (7) has been used in those studies. Figure 1 shows the life cycle stages of food products and the scope of this study. The figure indicates a general process tree for food products as it is used in such analyses. The

scope of our current study is indicated with a figure, and it indicates that the production of fertilizers and pesticides is not included in this study. LCA is a tool to determine the total environmental impact of products or services, one application of which is to compare the environmental impact of alternatives. The amount of each alternative should be such that both can fulfil the same functions. In LCA studies that amount is called a *functional unit*. It is sometimes hard to formulate such a functional unit. That is particularly true for those products, which have both a technical and an emotional function. Those functions are fully independent of each other and, therefore, may be represented as two perpendicular vectors. For food those vectors may represent the value of the nutritional and the emotional function, respectively. The resulting vector (Fig. 2) representing the function of the product, is determined by both length and direction, and may vary depending on the food product under study. Cooked pota-

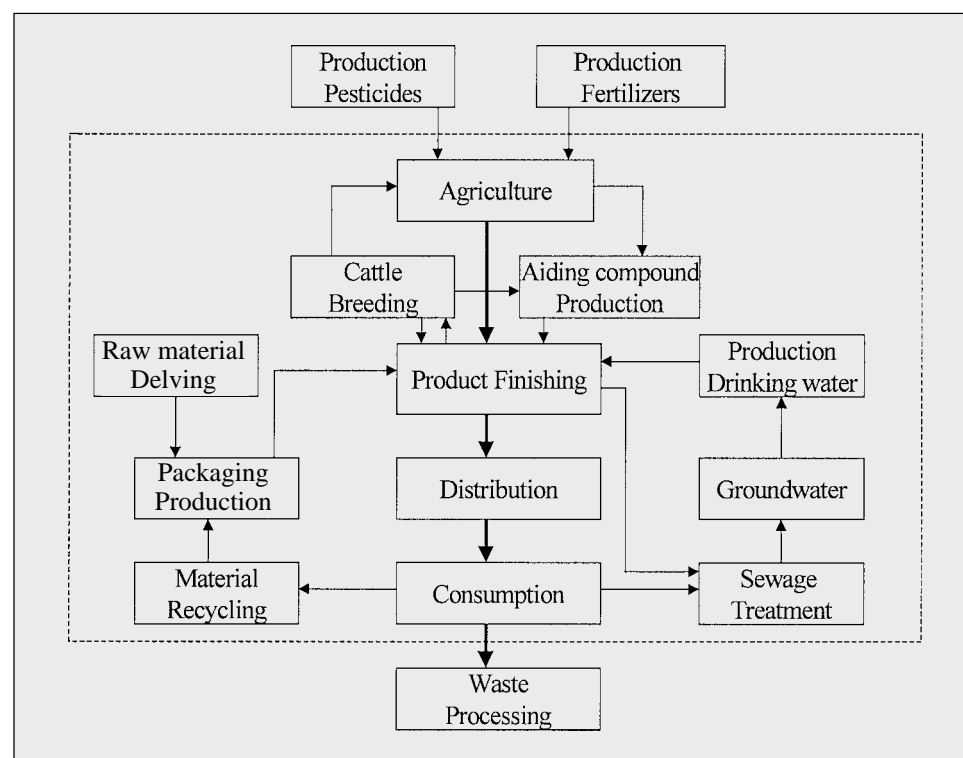


Figure 1. The life cycle of food products, with the scope of this article (dotted line).

Table 1. Energy requirement for some fresh ingredients from animal and vegetable Dutch origin (9).

	Energy requirement (MJ kg ⁻¹)
Vegetables	1–4
Fruit	2–5
Potatoes	1
Eggs	20
Milk	10
Butter/cheese	50–60
Fish ^a	20–40
Meat (poultry, pork, beef)	30–70

^a based on energy requirement for fishing, not fish farming

Table 2. Estimated energy requirement for transportation (10–12).

	Rail	(river) boat	(sea)boat	truck	plane
Energy requirement (MJ kg ⁻¹ 1000 km ⁻¹)	0.8	0.5	0.1	2–8 ^a	10

^a depending on size of truck

Table 3. Energy requirement for some preservation techniques as used by Unilever operations (1996 data).

	Energy requirement (MJ kg ⁻¹ end product)
Heat treatment (blanching/pasteurization/sterilization)	5–10
Freezing	5
Drying	0–15 ^a

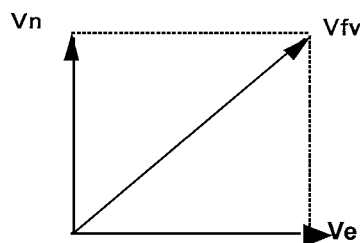
^a ranges from almost zero for sun-drying to about 15 MJ/kg for hot-air drying

toes would have a relatively high nutritional value and a low emotional value, while a chocolate bar has a high emotional value and a low nutritional value.

For the identification of improvement options, one should carefully choose a functional unit. For individual food products it seems to be hard to keep both dimensions constant, simultaneously, when changing individual components. As meals may strongly vary from day to day, the most appropriate functional unit for food may be a one-year consumption. That choice would, however, leave very little scope for identification of improvement options for individual components. Hence, as a first approximation, and for the sake of simplicity, in this article products are compared on a weight basis. That approach is in line with the constant average daily amount of food intake, as mentioned above.

Some generic patterns are highlighted in the energy consumption for the following stages of the life cycle: ingredient production, product manufacture/distribution, and consumption.

Figure 2. Functional unit for food (Vfv) as composed by a nutritional (Vn) and an emotional (Ve) component. On both axes there is an arbitrary scale.



Unless otherwise stated, the information used is based on Dutch data related to the mid-1990s.

RESULTS

Ingredient Production

Most food products are composed of agricultural and dairy produce, fruit, meat, eggs, and aiding compounds like emulsifiers, thickeners, and flavors. They are being transported between origin and food factories, or directly to the consumer. In most cases,

packaging materials are used for protection and easy handling. The various elements which contribute to the total energy consumption for each of these components are given below.

The energy requirements of food products differ for various food categories; even within a food category substantial differences exist. Various discriminating aspects can explain those differences, amongst which are several generic characteristics, such as vegetable *vs.* animal origin, open field *vs.* glasshouse and domestic *vs.* import. Each of these distinctions will be briefly dealt with below.

Vegetable vs. animal origin

In Table 1 the energy requirement is shown for some fresh ingredients from both animal and vegetable Dutch origin. The distinction between the energy requirement for both categories is about a factor 10, which is in line with observations from others (8).

On average, meat from fish has the lowest energy requirement, followed by poultry and pork. Beef has the highest energy requirement.

Open field vs. glasshouse

In many cases, glasshouses are used to control climatic changes. In southern countries, glasshouses are used to control conditions, but no additional energy is required. In northern countries, heating the glasshouses substantially increases both quality and yield. That procedure may increase the energy requirement by up to 40 MJ kg⁻¹ product (5).

Domestic vs. import (transport)

Most crops can only be harvested in a certain region during a limited period of the year. The consumer demand for such food components is usually not restricted to those periods, and hence products are transported from one region to another. Such transport has implications on the energy requirements, as can be seen in Table 2.

Product Manufacture and Distribution

Industrial food production generally includes various mixing and blending operations, as well as a preservation step. Particularly that last step requires a substantial amount of energy, as can be seen in Table 3.

Table 4. Energy requirement for the production of some packaging materials (13).

Material	Total energy content (MJ kg ⁻¹)	Recovery potential (MJ kg ⁻¹)
Paper/cardboard		
virgin	45	18
recycled (75%)	35	18
Glass		
virgin	13	–
recycled (100%)	10	–
Steel		
virgin	35	–
recycled (100%)	20	–
Aluminum		
virgin	195	–
recycled (50%)	100	–
Plastic	85	45

NB it is obvious that for a certain amount of food different amounts of packaging material are required, depending on the type of packaging material used.

Table 5. Average energy requirement for cooled/frozen storage as analyzed by Unilever in 1996–1997.

	Energy requirement (MJ kg ⁻¹ week ⁻¹)
Warehouse	0.01
Shop	1–10
At home	2–5

The wide ranges in the energy requirement for shops and at home is merely due to the variety of cooling and freezing cabinets, ranging from very well isolated facilities to small open boxes

Finished products are packed, which requires packaging materials. Specific products require special packaging materials in order to safeguard food integrity and safety. The choice for a packaging concept, both primary and secondary packaging, is usually based on a range of considerations, for which no general rules can be given. The energy requirement for some of the most commonly used packaging materials is given in Table 4.

The actual energy requirement depends on the waste treatment in a particular country, because of the energy recovery potential during waste incineration. In case all waste is incinerated with energy recovery the total energy requirement is reduced as shown in Table 4.

After production, the finished goods are stored and transferred to a shop. Some of the food products have to be kept cool or frozen during that process. In Table 5 energy requirements for the different options is shown.

Consumption

Consumers either consume their food outdoors, or they buy fresh or preserved food and take it home, in order to prepare and eat it after a certain storage time. In The Netherlands, on average, shopping adds 1–2 MJ kg⁻¹ as a result of the fact that 47% of all Dutch consumers use a car to do their supermarket shopping at a distance of about 6 km from their homes, assuming 20 kg of products is bought in one go (14). Dutch consumer habits seem to be not too different from those in other countries (e.g. 3).

In house, the food-related environmental impacts include: use of energy (gas and electricity) and generation of solid waste. At home, for various reasons, a significant amount of food is not consumed. Kooijman estimated that amount between 10 and 20% (6). A simple calculation may confirm that figure: the Dutch trade balance for vegetables, corrected for import, export and deliveries to industry, shows a possible consumption of 61 kg fresh vegetables per person for the year 1990 in The Netherlands (15). According to the real consumption of vegetables, a Dutch individual consumes about 47 kg (including frozen and conserved vegetables) per year (16). From these data the loss of vegetables from production to plate can be calculated at 20–25%. Material losses in the food industry are substantially lower, at 5% (4). Similar calculations with similar results can be made for meat products.

In order to compare the energy impact of food preparation,

three different elements have to be taken into consideration: *a*) storage; *b*) cooking; and *c*) waste generation. In Table 6, those elements have been summarized for three different types of preparation: *viz.* *i*) industrial; *ii*) restaurant; and *iii*) home cooking. For home-cooking, two options are mentioned, *viz.* *iii a*) preparation of home-made food; and *iii b*) re-heating of industrially prepared food.

DISCUSSION

The information in this article allows a rough estimate for the energy requirement of some major groups of food components by selecting the relevant elements from the production chain.

In a previous study, the total energy consumption was estimated for a large group of food components (4). In that study, the energy requirement was related to the market price. Although no correlation between those two elements was identified at the time, closer examination reveals a remarkable relationship. This holds for products as different as bread, fresh dairy (including regular cheese), most vegetables and fruit, margarine, eggs, and standard jam.

Roughly, the relationship between energy consumption and price is about 5 MJ for each Dfl (1994 prices) (1.6 Dfl ≈ 1 USD). Products that are relatively cheap compared to their energy consumption include glasshouse vegetables (tomato and cucumber) at about 20 MJ Dfl⁻¹, dried products (e.g. dried vegetables) at 10 MJ Dfl⁻¹, butter and fresh meat. Products that cost more than their relative energy-consumption have a high added emotional value, e.g. wine and beer (3–4 MJ Dfl⁻¹), season fruit/vegetables (2–3 MJ Dfl⁻¹) and coffee/cocoa or tea (2–3 MJ Dfl⁻¹). A similar conclusion can be drawn from a lifestyle study by Biesiot and Moll, in which the cumulative food expenditure in Dutch households has been expressed as a function of the energy-intensity of the food products (19). Their observations show that the bulk of food expenditure lies at an energy-intensity of between 4 and 6 MJ Dfl⁻¹.

As soon as some emotional value is added to the food product somewhere in the chain, this is reflected in the price, but not in the energy requirement. This is true for exclusive products (e.g. first flush tea, Beaujolais première), for branded products, and for prepared meals, either sold in the supermarket or consumed outdoors. In all cases energy/price ratios of significantly less than 5 MJ Dfl⁻¹ are observed. In case energy costs are dis-

Table 6. Indication of environmental impacts during preparation of food (5, 17, 18).

	storage (MJ kg ⁻¹)	cooking (MJ kg ⁻¹)	waste
Factory production	0.01	5–10 ^a	5%
Restaurant	1–2	10–15	10–20%
Home			
Home-made	1–3	5–7	10–20%
Home-finished (heated)	1–3	1–2	5–10%

^a of Table 3 in this article

torted by political decisions (e.g. no energy tax for glasshouse crops in The Netherlands), the energy-cost ratio rises well above 5 MJ Dfl⁻¹.

CONCLUSION

The information described in this article indicates that there is no systematic environmental benefit for homemade over industrially-produced food. This is in line with other observation (e.g. 20).

For all food categories there is a wide variety in energy requirement due to three major factors:

- i) Season of consumption; which relates to storage, transportation and glasshouse production.
- ii) Scale of preparation; which relates to process energy and material losses.
- iii) Consumer behavior which relates to choices, storage and preparation.

As can be concluded from the information provided in this paper, improvement options may be found in each of these areas. For example, the consumption of regional crops from the field and consumption of vegetables instead of meat usually decreases the overall energy consumption in the food chain.

As argued at the beginning of this article, the functional unit for food is composed of two elements, *viz.* a nutritional and an emotional one. For basic food components there is a good relationship between energy requirement and market price. As soon as emotional value is added that relationship deteriorates, confirming that the market value of a food product is also based on two elements, a functional and an emotional one. This only reinforces the idea that at least for food products, a close relationship exists between functional unit and market price.

The fact that home-made food is considered by some as environmentally friendly, in spite of the fact that objective measurements do not support this claim, may be explained by the relatively large contribution of personal satisfaction in preparing one's own food to the functional unit of food.

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