The Effect of Food Consumption and Production Trends on Energy, Greenhouse Gas Emissions and Land Use

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Abstract

In this report we assess the trends in food consumption and food-related environmental impacts (in terms of energy use, greenhouse gas emissions and land use) for three regions: Western Europe, the USA and China. The environmental impacts were determined by two methods: a product level analysis, in which the energy and emissions per kilogramme of 19 products was calculated; and a system level analysis, in which the energy use and emissions of each stage in the process chain (i.e. agriculture, fertilizer manufacture, food processing, transportation and packaging) was assessed for all food products combined. The energy use and GHG emissions for the entire food system (from cradle to factory gate), were estimated at 12.0 MJ/cap and 1.97 $tCO_{2\text{-eq}}$/cap in Western Europe; 15.1 MJ/cap and 2.83 $tCO_{2\text{-eq}}$/cap in the USA; and 4.1 MJ/cap and 0.88 $tCO_{2\text{-eq}}$/cap in China for 2000. In the developed regions, per capita energy use has increased on average around 1% per year since 1970, whereas in China it has increased more than twice as rapidly. Per capita greenhouse gas emissions from the food system have declined slightly from 1970 levels in the USA and have remained unchanged in Western Europe, however they have increased at an average rate of 1.6% per year in China. The diverging trend in energy and GHG emissions can be traced to non-energy sources of emissions during agriculture. Stabilizing cattle populations and fertilizer application rates in Western Europe and the USA have held back the growth of agricultural emissions, which accounted for 60% of emissions from the food system in Western Europe in 2000. Non-grazing land use has also stabilized in Western Europe and the USA as yield improvements have kept pace with population increases and consumption pattern shifts. In China the rapid increase of meat consumption – from 9kg/cap in 1970 to 47 kg/cap in 2000 – has outweighed yield improvements, resulting in an increasing requirement for land. A significant share of the increasing land used for oil seed production is taking place abroad. Scenarios were developed for the future, revealing that, if the current trends continue, per capita energy use will increase by 30-40% between 2000 and 2050 in the developed regions and by over 200% in China. The increase is driven by transport and processing stages. The environmental impact of the food system can be reduced through consumption changes of high-impact foods, especially beef, which has a disproportionately large impact during agriculture. Furthermore, increased attention should be given to measures that reduce emissions during agriculture, because this stage is so large. Action should be taken to limit the growth of energy use and emissions in the transport and processing stages, as they are on track to increase strongly in the future.

Contents

1 Introduction

Food is the quintessential human-environment interaction. Throughout history, humans have succeeded in exerting greater control, undergoing a transition from hunter gatherer to agrarian, and more recently, to industrialised societies. The food supply has increased accordingly, and is now abundant enough to provide for the world's population of over six and a half billion[1] (although that is certainly not to suggest the entire population receives an adequate share). The vast increase in food supply was made possible primarily through the expanding use of fossil fuel-based energy (Odum, 1971). Great yield increases were realised as mechanical equipment replaced human and animal power on the farm and fertilizers were produced in the factory.

This transition to an industrialised, fossil fuel powered society has yielded drastic changes, not only for humans, but also for the environment. Environmental change has always been with us, however the changes that occur today are dominated primarily by human activity, in contrast to early human history when they were caused more so by natural processes (Messerli, 2000). Over the past few decades, growing attention to environmental degradation and humanity's role in exacerbating it has resulted in a number of international initiatives aimed at promoting sustainable development[2], notably the World Conference on Environment and Development in 1992 (Rio de Janeiro) and the World Summit on Sustainable Development in 2002 (Johannesburg).

At the heart of sustainable development is ensuring an ample and equitable supply of food, the most basic of human needs, without endangering future generations' access to it. This has vastly different meanings in different regions of the world. In developing countries, chronic hunger is the overwhelming priority, with over 800 million people affected in total (UN, 2006a). On the other hand, developed countries have effectively eliminated chronic hunger. Attention can shift to health and safety on the consumption side, as well as minimizing the environmental burden of food production. Key to the latter is reducing energy use and greenhouse gas emissions, and using land in a more sustainable manner.

Assessments of energy use and emissions are typically framed on a sectoral basis (Bin and Dowlatabadi, 2005). For example, the International Energy Agency in its world energy balance distinguishes between energy consumption by the industry sector, transport sector, etc (see Figure 1). However, this approach is of limited use when it comes to assessing the entire food system, as it is composed directly or indirectly of processes within virtually all sectors. A more suitable division of the economy would be between final demand categories i.e., according to their purpose, which together add up to the total final consumption of the economy as a whole. One example of final product

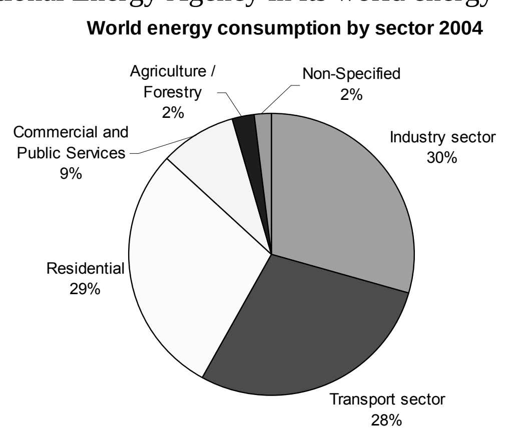

Figure 1: Total final energy consumption by sector. Source: IEA, 2006

[1] FAOSTAT food balance sheet (2006a) for the world indicates that for the years 2000-2003, the average per capita daily availability was 2798 kilocalories, whereas the minimum dietary energy requirement is estimated to be around 1800-2000 kcal/person/day.

[2] Sustainable Development, defined by the Brundtland Report to the WCED, is development that meets the needs of the present without compromising the needs of future generations (Brundtland, 1987).

categories is given by the Classification of Individual Consumption by Purpose (COICOP) from the United Nations, in which food and beverages are distinguished from housing, education, clothing, etc. Because all economic activities are ultimately initiated for consumption, all of the environmental impacts can be attributed to categories at this level. Several studies have assessed the environmental impacts of these final products (e.g. Nijdam and Wilting, 2003; Tukker et. al, 2006; and Moll et al., 2005) using a top-down or hybrid approach, with input/output methods for data inventory (Tukker and Jansen, 2006). These studies reveal that, with respect to the economy as a whole, the food system is among the most important of all categories (along with housing and transport), typically responsible for a fifth to a third of all environmental impacts[3].

Other studies have looked specifically at the food system at the (supra) national level (e.g. Ramirez, 2005; Heller and Keoleian, 2003), revealing the stages where the impact is greatest and, in the former case, showing how the impacts have changed over time. Bottom up studies (e.g. Carlsson-Kanyama et al., 2003) have also contributed greatly to our understanding of the food system by showing the differences between individual food products and between consumption patterns (in a single country/region).

However there exist some gaps in the research which we attempt to fill here. The studies mentioned above focus on only one particular country or region, and because of different scopes and methods, they are not strictly comparable. Furthermore, changes over time are largely neglected (with the exception of Ramirez, 2005). Here we will examine the regional differences as well as variations in the past for Western Europe, the USA and China. In doing so, we will gain insight into what drives the temporal and regional differences. For example, are differences in consumption patterns (e.g. more meat consumption in one region) the main reason for higher environmental impact in that region, or are the differences more due to structural characteristics (e.g. transport distances). We will also develop scenario projections for the three regions until 2050. All these elements are important for scientists, policy makers and indeed anyone interested in planning a sustainable food system.

1.1 Approach

We employ life-cycle assessment (LCA) as a framework for analysis. LCA is used to evaluate the environmental burdens associated with life cycles of materials and services (Todd/SETAC, 1999). It is not currently feasible to apply a complete LCA to the entire food chain because of the enormous amount of data that would be needed. Nonetheless using an LCA framework and limiting it to only few indicators for a limited number of product groups will allow us to examine, in a systematic way, the impacts associated with all stages in the food system (including primary production, processing and consumption), so as to avoid neglecting additional burdens that may occur in unexamined stages.

LCA methodology consists of at least three phases: goal and scope definition, inventory analysis and impact assessment (Baumann, 2004). The goal if this study is to compare the environmental impact of food consumption in Western Europe with those in the USA and China, and to determine what drives the differences. Consequently, we are concerned with the impacts that occur as a result of the foods eaten in the regions, wherever production occurs. Note that this is a departure from other studies that focus on production in a given region, regardless of whether the food is consumed domestically or destined for export. Examining the impact from the

[3] Food related impacts according to Nijdam and Wilting (2003): 30% of greenhouse gas emission and 56% of land use; Tukker et al. (2006): 21% of abiotic depletion, 29% of global warming; Moll: et al. (2005) 15% of energy use.

consumption point of view includes the impacts that arise from trade, an important aspect that is growing in importance.

The system boundaries include the following stages: agricultural production, fertilizer production, food processing, packaging, and transport of food during production and processing. Not included are production of capital goods, transport of fertilizers, transport from retail outlets to the home, distribution and waste management, which are known not to be significant, and household use and storage, which is significant. With respect to the geographic scope, comparing Western Europe to the USA and China enables us to contrast two developed regions and one (rapidly developing) region. The time frame stretches back to 1960, although data is not always available reaching back that far. For convenience of presentation, we typically show the situation for 1970, 1990 and 2000. One point of clarification is necessary about Western Europe. Due to data availability, it was far more convenient to relax the system boundaries to allow some flexibility in the countries included in Western Europe. Hence Western Europe may at times refer to the EU-15, EFTA-19, OECD Europe[4] and when necessary a few carefully chosen countries to represent the region. It is hoped that by carrying out calculations and reporting on a per capita basis much of the negative impacts of this decision will be avoided.

The inventory analysis will be based on a bottom-up strategy, using existing LCAs for individual food products. These will be adjusted for each region using top-down analyses of each stage in the life cycle. The impact assessment will be limited to three domains: energy use, climate change (global warming potentials from greenhouse gas emissions) and land use. Energy is examined in terms of primary energy; GHG emissions as CO_2 equivalents using global warming potentials for a 100 year time horizon (from IPCC, 2001), focusing on carbon dioxide, methane, and dinitrogen oxide.

LCA framework is useful for allocating the environmental impacts in a systematic manner. In order to better identify the driving factors of different impacts, we split the food system into a consumption and a production side – into demand and supply. Of course these are closely interlinked, but splitting them offers some advantages. We can see what effect changes in diet can have compared to changes in production. This can lead to insights into the potential of efforts to improve the environmental impact of the food system.

We begin in Section 2 by determining the differences in consumption patterns for the three regions, how they have changed over time and what is driving these changes. Section 3 examines regional differences and temporal changes in the food production and supply. The environmental impacts – energy use, greenhouse gas emissions and land use – are compiled for food consumption and production in Section 4. In Section 5 we apply these results to create a possible scenario for the future. Finally, in Section 6 a discussion of the results and the conclusions are presented.

[4] European Union (EU) 15 countries include Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom. EFTA-19 includes EU-15 countries plus Iceland, Liechtenstein, Norway and Switzerland. OECD Europe includes the EFTA-19 plus Czech Republic, Hungary, Poland and the Slovak Republic.

2 Consumption Patterns

Food consumption can be defined in a two ways: as the amount of food which is taken in by humans, henceforth referred to as intake, or as the amount of food which is available for humans to consume, known as availability. Availability differs from intake in that the former includes food loss which occurs in the household and at food service establishments such as canteens and restaurants (e.g. waste from storage, preparation and plate waste). Availability is said to measure consumption at the household/food service level whereas intake measures consumption at the individual level.

Most data that can be compared internationally are available at the household level. At this level, the food availability can be calculated either by surveying households (household budget surveys – HBS) or by balancing other measured statistics (e.g. statistics on production, import, export, own use and waste) for a country or region as a whole (food balance sheets – FBS). The Food and Agricultural Organisation of the United Nations (FAO) has compiled FBS for most countries in the world onwards from 1961 (FAOSTAT, 2007). Because of the consistency of information and international comparability, this will serve as the basis for comparing consumption patterns[5].

The food products in the FBS are generally expressed in primary (or near primary) equivalents (for example milk in FAO FBS would include cheese products as well as liquid milk). However in order to determine environmental impacts throughout the entire life cycle, we are also interested in the state of the final food products such as processed vegetables or processed meat. Because there is no comprehensive source of comparable data for these products, we use varying sources among regions to estimate the final product mix[6] when relevant to the environmental impact. The sources were: For Western Europe, the Data Food Networking (DAFNE) databank (DafneSoft, 2007), a harmonised collection of European HBS; for the USA, FBS from the Food Availability Data System (ERS, 2007a), which is derived from food balances; and for China, no source was found that contained adequate information, so rough estimates were made in order to evaluate the environmental impact, informed by NBSC (2007) and Du et al. (2002).

Unfortunately data for all Western European countries were not available in the DAFNE databank. Four countries – UK, Spain, France and Greece - were selected and assumed that their average consumption per capita was indicative of the entire region. These countries were chosen primarily because of data availability over time.

[5] FAO data for Western Europe were gathered for EFTA-19.

[6] FAO FBS typically differ substantially – 20 to 35% – from HBS in the total food availability reported (see Appendix 1C). FAO FBS also differ from the US administered FBS from the Food Availability Data System, albeit to a lesser extent (less than 5%), mostly due to difference in the state at which food products are reported. Because these differences exist, the availability at the final product level could not be directly combined with FAO FBS values. To overcome this discrepancy, we divided the weight of the processed product, e.g. cheese, as reported by DAFNE or ERS, by the total availability of dairy products, also reported by DAFNE or ERS (the weights were converted to primary equivalent). This ratio was then used to break down the availability at the primary level according to FAO FBS values.

2.1 Trends in primary food commodities

Figure 2 shows some trends in availability from FAO FBS for the most important food commodities relative to environmental impact (more detailed data can be found in the Appendix). The notable trends are as follows:

- The difference in cereal and starchy root availability between regions is relatively small – in recent years the difference has been around 10%, as the regions have converged strongly around the world average between 213 and 223 kg/cap.
- Fruit and vegetable availability has grown significantly across all regions to the point where more kilograms of fruits and vegetables are consumed in the regions than cereals and starch roots. The growth in fruits and vegetable availability has been especially strong in developing countries, narrowing the gap between them and developed countries to less than 20%, to a large extent on account of China[7], which has even recently surpassed USA levels.
- Meat availability has also grown strongly across regions, while the level and pattern of consumption differs substantially in the regions studied. For example, the US availability has remained 3-4 times higher than the world average and Western Europe at 2-3 times above the average over the entire period, without much indication of convergence. Western Europe and the USA have increased their meat availability by around 1% per year over the entire time period China, meanwhile, has nearly quintupled its meat consumption since 1980. Meat availability in the developed world seems to be saturating at different levels, with Western Europe at around 90 kg/cap and the USA at or above 120 kg/cap.
- Milk availability also varies widely between regions, with the USA and Western Europe more than three times the world average and more than five times China's level.
- There is a large difference between the availability of sugar and sweeteners in the three regions; China is remarkably low. However rising consumption of sugar and sweeteners is characteristic of nutrition transitions as is occurring now in China (Popkin, 1994). The USA and Western Europe appear to be saturating at significantly different levels.
- In all regions, on the whole, animal products have grown at a stronger rate than plant products.

[7] China's fruit and vegetable availability may seem extremely high, but in comparison with Mediterranean countries such as Greece, whose consumption in 2003 was 423 kg/cap, it is not necessarily exceptional. However, data from Chinese HBS do not show the spectacular increase that the FAO FBS show: According to the Chinese Health and Nutrition Survey - as reported by Du et al. (2002) - 143 kg/cap of fruits and vegetables were available in 1989, which then dropped slightly to 134 kg/cap in 1997. FAO FBS on the other hand reported 114 kg/cap in 1989 and 212 kg/cap in 1997. Perhaps an explanation for the rapid growth in FAO FBS data is that own-grown food is often underreported in FBS statistics. Rural Chinese consumed very high quantities of vegetables, much higher than urban households (Popkin et al., 2002), if these vegetables were own-grown then they would tend to be underreported in early years. As time has passed and an increasing share of the population has moved to urban localities, reporting has gotten better.

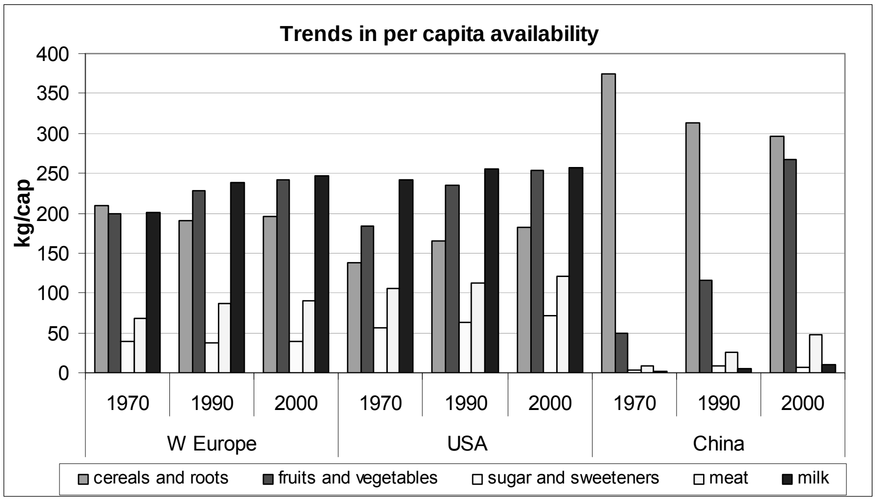

Figure 2: Food availability of major commodity groups in Western Europe, the USA and China. Source: FAOSTAT, 2007

Of the major food groupings, the meat category shows the most significant variation within the group (at the primary commodity level). A close examination of this category is especially relevant because of the large environmental impact associated with it (see Section 4). As Figure 3 shows, availability of pig and poultry meat has generally grown strongly, meanwhile bovine and other meat has remained flat. In fact, the growth in meat consumption can be attributed primarily to poultry and pork increases. For example, worldwide, the average annual growth rate (per capita) from 1961 to 2003 has been 3.5% for poultry and 1.6% for pork, compared to 0.1% for bovine meat.

However there are some important differences between regions. In the USA, pig meat availability has remained constant at around 25 kg/cap. In Western Europe, on the other hand, pig meat increased throughout the 1960s and 70s, before levelling off at above 40 kg/cap. China experienced explosive growth, even surpassing pork levels in the USA. Poultry meat has grown very rapidly across regions. Once again, though, there is a large separation between regions, with the USA reaching 50 kg/cap, a level 2 times higher than Western Europe and 4 times higher than developing countries. Bovine meat has grown relatively slowly or not at all across the regions. The saturation level is highest in the USA at around 40 kg/cap, after having decreased from beyond 50 kg/cap between 1970 and 1990; in Western Europe it is around 20 kg/cap.

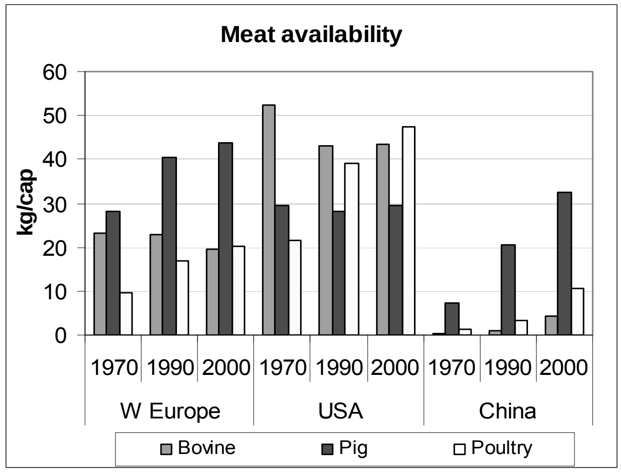

Figure 3: Trends in meat availability in selected regions. Source: FAO, 2007

2.2 Trends in final food products

Turning to food consumption at the final product level, first we take a look at the break down of products that will be used later in constructing the environmental assessment. Table 1 shows the allocation of final products for their respective commodity group[8]. For example, 17% of fruit products (by weight) in Western Europe in 2000 were in the form of fruit juice.

From Table 1 we can get a peek at some trends in final products. First, it is evident that fresh and minimally processed foods are still dominant in many categories. Fresh fruits and vegetables are near 80% in Western Europe and minimally processed meat makes up over 60-70% of meat products in Western Europe and the USA. However, there is a considerable degree of separation in terms of processed food saturation levels. In the USA, processed fruits and vegetables combined account for upwards of 100 kg/cap/a, whereas in Western Europe it is around a quarter of that (including frozen, canned, juice, etc.).

[8] Other products not shown in Table 1 will also be included in the assessment, but information at the raw level is sufficient (e.g. bovine meat).

Table 1: Share of final products in commodity group. Source: Own calculations based on DAFNE, 2007; ERS, 2007a; Wiegmann, 2005

		W Europe 1970	1990	2000	USA 1970	1990	2000	China 1970-2000
Cereals	Wheat Bread	0.75	0.69	0.64	0.73	0.70	0.69	0
	Pasta/noodles	0.08	0.09	0.10	0.05	0.08	0.09	1
Starchy	Fresh potatoes	0.65	0.58	0.55	0.51	0.38	0.34	1
Roots	Frozen/processed	0.35	0.42	0.45	0.49	0.62	0.66	0
Vegetables	Average fresh.	0.83	0.83	0.80	0.43	0.47	0.53	0.95
	Average frozen	0.03	0.06	0.06	0.07	0.08	0.08	0
	Average canned	0.14	0.11	0.13	0.46	0.42	0.36	0.05
Fruits	Average fresh	0.90	0.83	0.80	0.42	0.43	0.45	1
	Average juice	0.05	0.13	0.17	0.41	0.44	0.43	0
Dairy	Milk (drinking)	0.50	0.46	0.48	0.64	0.52	0.42	1
	Cheese	0.40	0.45	0.42	0.16	0.35	0.48	0
Meat	Highly processed products	0.30	0.32	0.34	0.34	0.36	0.38	0.1

Note: own estimates are shaded - for Western Europe they are based on trends from UK data (DEFRA, 2007) and Wiegmann (2005), and trends in the USA; for the USA they are based on a US household budget survey CSFI (USDA, 1997) and Western Europe trends; for China they are very rough. Note 2: Product shares within commodity groups often do not sum to one because other products, e.g. dried fruit, make up a small portion within the group.

Closely associated with the degree of processing is the trend towards increasing convenience products. Ready meals are a notable convenience product that has increased quite strongly and continues to do so. GMID (2006) reports that ready meals have increased at an average annual rate of 2.5%. However, this category represents only a small share of food availability - 5 kg/cap for Western Europe (GMID, 2006). The growth in food service is also a sign of more convenience. In the USA, for example, in 1977 19% of calories were consumed away from home. By 1995 this had increased to 34% (OECD, 2001)[9]. Western Europe has not yet reached such high levels. In the UK, for example, 9% of food calories were consumed away from home in 2003/4 (DEFRA, 2007).

An increase in diversity of food products is also a trend commonly identified, as evidenced by an increase in new products and a growth in food retailer size. See Appendix 1 for more information.

2.3 Food loss

Another important aspect of the food system is the amount that is lost. We distinguish between food loss, where a portion of the potential edible supply is not utilized (e.g., discarded table scraps and spoiled produce), and waste that is not consumable (e.g., inedible offal and husks). The former will be examined here.

Losses occur at all stages, yet no reliable data exist for losses throughout the entire food system. There are a number of reasons for this: the complexity of material flows within the food sector and between sectors; measurement problems, especially with household losses; and hidden losses, sometimes accompanying discards because of price controls or disease controls (FAO,

[9] In terms of expenditures, in 1977 38.7% of US total food dollars was spent on away-from-home food, increasing to 46.5% in 1995 and 48.6% in 2005 (ERS, 2007c)

2007). The available data are not consistent or comprehensive enough to construct a complete picture of food loss across countries or time. Instead, the best that can be achieved at this point is an overview of the contribution of the stages and a rough estimation of the extent of food losses.

Table 2 and Table 3 show estimates of losses as a percentage of supply at different stages of the food system. These estimates indicate that losses at the household stage are most significant, and for some categories can approach 30%. At the transport and storage stage, perishable foods, i.e. fruits, vegetables and starchy roots, are also significant. The factors contributing to these losses are different in developed and developing countries. In the latter, a lack of appropriate technology and storage facilities are a major concern. This is especially true for perishable items which require rapid distribution chain from farm to consumer, and/or proper temperature management. In this respect climate plays an important role in post-harvest losses. Regions with high temperatures and humid conditions are more suitable for insect pests and micro-organisms, resulting in a higher vulnerability to storage losses (Grolleaud, 2002). On the other hand, developed countries with a high level of technology are not immune to losses at this stage, where many losses can be traced to production surpluses and excessive quality grading (FAO and UNEP, 1981).

Table 2: Transport and storage losses [% of supply], 1992-1996. Source: FAO, 2000

		Western Europe			USA	China
		UK	Fr	D		
Cereals	Wheat	0.5	0.8	1.6	n/a	11
	Rice	n/a	n/a	1	9.3	8.8
Roots	potatoes	11	7.5	5	3	5
Oilseeds	Soybeans	n/a	n/a	0.6	5	3.1
Vegetables	Tomato	0.3	7.8	15	10	7
	Onion	2.2	14	10	5	10
Fruits	Apples	0.3	4.8	6	5	10
	Bananas	5	5	6	5	10
	Oranges	5	10	4	2	10

Table 3: Estimates of USA food loss at the household stage [% of supply][10], 1995. Source data: Kantor et al., 1997

	Household/food service loss % of supply
Cereal grains	5
Fruits, vegetables and potatoes	20
Meat	15
Dairy	28
Sugar and sweeteners	28
Oils and fats	23

2.4 Drivers

Underlying the shifting consumption patterns is economic development. Economic growth triggers changes in food consumption patterns, with countries at higher levels of income able to

[10] Estimates from Kantor et al. were based on percentages of food availability. We converted this to supply by dividing the estimated food loss (in kg/cap) by the supply (also in kg/cap) from FAO food balances.

produce and consume higher value food items, satisfying their demand for certain attributes in food (such as convenience, health, variety) beyond basic nutritional requirements. As Popkin (1994) outlines, the following dietary patterns changes occur as countries progress in their economic development:

- As countries industrialize, the dominance of cereals is reduced and fruits and vegetable consumption increases along with animal protein intake, although a less varied diet persists.
- As income grows further and the economy increases in service orientation (also household technology is mechanised), diets increase in animal products, sugar and processed foods
- As the economy moves toward mechanised service sector and robotised industry and income growth slows, there is an increase in fresh foods and in fruits and vegetables, reduced meat and dairy.

Economic development can be seen in the growth in per capita income as shown in Figure 4. The US and Western Europe have of course been at the fore in this development, and there are indications that they are progressing towards Popkin's latest stage. China is rapidly ascending, approaching income levels of Western Europe in the 1960s (on PPP basis). It would be expected then that consumption levels in China after 2000 would show also approach European levels in the 1960s/70s. This is roughly the case for overall consumption of meat and cereal products in comparison, however not for milk products or fruit and vegetables (see Figure 2). Perhaps more important than absolute levels are the transitions, because the starting points of the various countries are so different owing to a variety of factors (e.g. culture and climate).

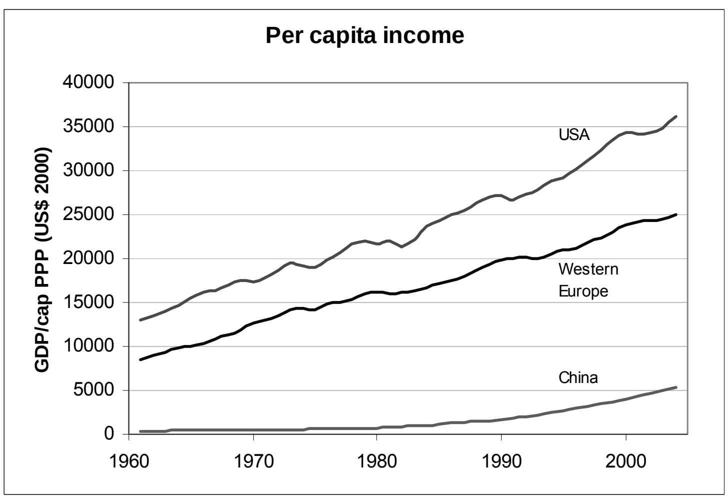

Figure 4: Trends in real GDP/capita in selected regions, PPP adjusted. Source: Heston, 2006

Additionally, within each country, differences can be observed according to income, with low income households in developed countries tending to consume more animal products and less fruits and vegetables (with the exception of meat in the USA). In developing countries, low income households rely much more heavily on cereals and consume far lower levels of animal products, especially meat. The differences among households within countries are particularly relevant because over the course income inequality within countries has increased significantly[11].

[11] One measure of income inequality is the Gini index, with higher values indicating more inequality. The Gini index of the USA increased from 39 to 49 from 1970 to 1998, China increased from 29 to 40 from 1980 to 2000, and the UK increased from 30 to 38 from 1980 to 2000 (WIID2, 2004)

Table 4 shows these differences in food consumption as reported by three HBS. Although the differences are present in the UK and USA, they are far more pronounced in China. Furthermore, the differences between the countries are larger than differences within countries. The stage of economic development can be seen as a stronger driving force than household income.

Table 4: Differences in food consumption by income groups [kg/cap/yr]. Sources: DEFRA, 2007b; USDA, 1997; Du et al., 2004.

<table>
<tr><th></th><th colspan="3">China 1987-1997</th><th colspan="3">UK 2002-2005</th><th colspan="3">USA 1994-1996</th></tr>
<tr><th></th><th colspan="3">Weekly HH income</th><th colspan="3">Weekly HH income (2004£)</th><th colspan="3">Weekly HH income (1995$)</th></tr>
<tr><th>[kg/cap/yr]</th><th>low</th><th>mid</th><th>high</th><th><205</th><th>357-579</th><th>>885</th><th><286</th><th>286-735</th><th>>735</th></tr>
<tr><td>meat</td><td rowspan="2">25.8</td><td rowspan="2">44.1</td><td rowspan="2">64.4</td><td>55.6</td><td>54.2</td><td>53.7</td><td>69.4</td><td>71.2</td><td>73.4</td></tr>
<tr><td>dairy</td><td>124.1</td><td>111.8</td><td>100.7</td><td>105.9</td><td>100.0</td><td>97.1</td></tr>
<tr><td>fruits and vegetables</td><td>n/a</td><td>n/a</td><td>n/a</td><td>160.4</td><td>159.1</td><td>168.5</td><td>114.6</td><td>127.8</td><td>141.6</td></tr>
<tr><td>cereals and starchy roots</td><td>193.9</td><td>178.5</td><td>158.7</td><td>124.6</td><td>115.7</td><td>107.5</td><td>130.7</td><td>130.7</td><td>136.1</td></tr>
</table>

Note: The values of the weekly household income for the UK and the USA represent deflated, nominal values (expressed in terms of market exchange rates). The values have not been corrected for purchasing power parities (PPP).

Alterations in the size and organisation of families have led to greater time constraints and consequent increase in demand for convenience. Time spent on food preparation has in general decreased substantially since the 1960s – in the USA from 44 minutes per adult per day to 31, and from 57 to 41 minutes in the UK – however there is a levelling out in the USA and Western Europe in the past decade.

A significant factor causing this (real or perceived) time scarcity has been the increase in women's participation in the workforce. Figure 5 shows the significant increase over the past 30 years especially in Western countries. Also shown in Figure 5, the average household size has decreased sharply, which has caused further time constraints as less preparation time per person is required for larger households. The result on consumption patterns has been a decrease in time-intensive foods such as minimally processed cereals, and an increase in convenience food items such as ready meals and in away-from-home dining[12].

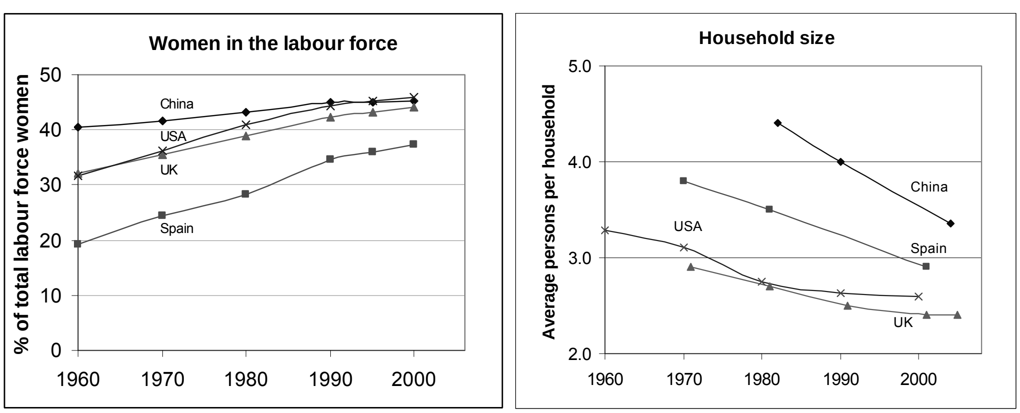

Figure 5: Demographic trends in selected countries. Source: UN Common database

[12] It is important to note that the ability of consumers to purchase these foods has also increased as incomes have risen. Determining exactly how much can be attributed to income and how much to the changing demographics of the population is not practical on account of data inaccuracy and multicollinearity; however it is clear that both are play important roles.

Demand is also influenced heavily by health concerns. Over the past couple decades, awareness of the relationship between diet and health has increased, especially with regard to fruit and vegetable intake (Guthrie et al., 2000). Education and age influence awareness, with higher education and older age correlated to better improved nutritional knowledge and health awareness (Massari, 2003). Furthermore, food scares and disease outbreaks have an immediate effect on consumer behaviour, e.g. a decline in beef consumption in the Europe after BSE outbreak. While health concerns have worked to increase consumption of fresh foods, mass advertising has pushed for greater processed food purchases. In 1997 in the USA, $7 billion was spent on food advertising, most of which is focused on highly processed, highly branded products, in comparison with a third of a billion on education and associated activities by the USDA (OECD, 2001).

Urbanisation has also been an important driving force, with changes especially large in the developing world. From 1980 to 2005, China transitioned from 20% of the population in urban areas to 40% (UN Common database, 2007). Urban populations have easier access to a variety of food compared to rural populations, which often produce much of their own food. For example, Wu (1999, from Regmi, 2001) estimates that rural households in China produce 50% of their own food. However, urbanisation is also closely linked with other drivers - urban populations have higher incomes, smaller family size, and a greater portion of women working outside of the home. All of these factors combine to result in urban populations consuming a greater variety of food items, more fruit, vegetables and meat, fewer cereals, more processed food and away-from-home eating. The difference in consumption patterns between urban and rural is greater in developing countries than developed (Regmi, 2001).

3 Trade and supply structure trends

In this section we turn to trends on the production side. First, we examine trade, so that the impacts of consumption can be properly allocated, followed by agriculture, packaging and transport.

3.1 Trade

Our focus here is on consumption in the regions rather than production. However much of the information in the supply stages of food is available for regional production. For example the consumption of fertilizers in Western Europe is known, not the consumption of fertilizers that are inputs for the food eaten there. In this respect, it becomes important to examine the trade balances so that adjustments to the production data can be made.

From UN Comtrade data[13] (2007) we determined the amount of food and feed imported and the net balance of imports minus exports, henceforth called net imports, as shown in Figure 6. For most food commodities, we assumed all imports were allocated to food use. This was justifiable because animal feed, the largest other use of food-related commodities, was reported separately. The exceptions were unmilled cereals and oilseeds, which were reported as such and may be used in significant shares for animal feed or other industries. In order to allocate the mass of these commodities between food, feed and other uses, we used percentages of total supply from FAO food balances.

The USA has historically (since before the 1960s) been a primary exporter (worldwide) of cereals and animal feed, whereas Western Europe a major importer. However, regarding cereals, Western Europe introduced price supports towards the end of the 1970s in its Common Agricultural Policy, which led to large increases in domestic production, and consequently a drastic drop in imports (Whitton, 2004). By the middle of the 1980s, Western Europe had become a net exporter of cereals, peaking in the 1990s at around 60 kg/cap net exported. Since then imports have once again grown and the trade of cereals in Western Europe is close to balanced.

Imports of grains have dropped significantly in China from 1990 to 2000 (although compared to other regions the magnitude is rather small), somewhat unexpectedly considering the liberalization of trade in general and the trends for oilseeds in particular[14]. The reason for this change has been a reversal of grain policy, which, prior to the late 1990s, was focused on securing adequate domestic supply. However a large surplus developed as a result of declining demand, increased production and imports. The response was a policy shift that no longer encouraged overproduction of cereals, followed by a correction for the oversupply (Gale et al., 2001).

On a per capita basis, Chinese trade seems rather insignificant. However one must keep in mind the large size of the population. In absolute terms, China has, as of 2005, surpassed the

[13] UN COMTRADE classification SITC Rev. 1 was used because data were available for this classification beginning in 1962. Intra-Western European trade was excluded.
[14] As a whole, China's agricultural imports have not experienced the enormous growth seen in other sectors. See Appendix 3 for more information.

European Union as the largest importer of oilseeds[15] (see Appendix 3 for absolute (net) imports). But keeping the focus on per capita figures, the gap between Western Europe and the USA on one hand, and China on the other, illustrates the enormous potential for growth that exists in China.

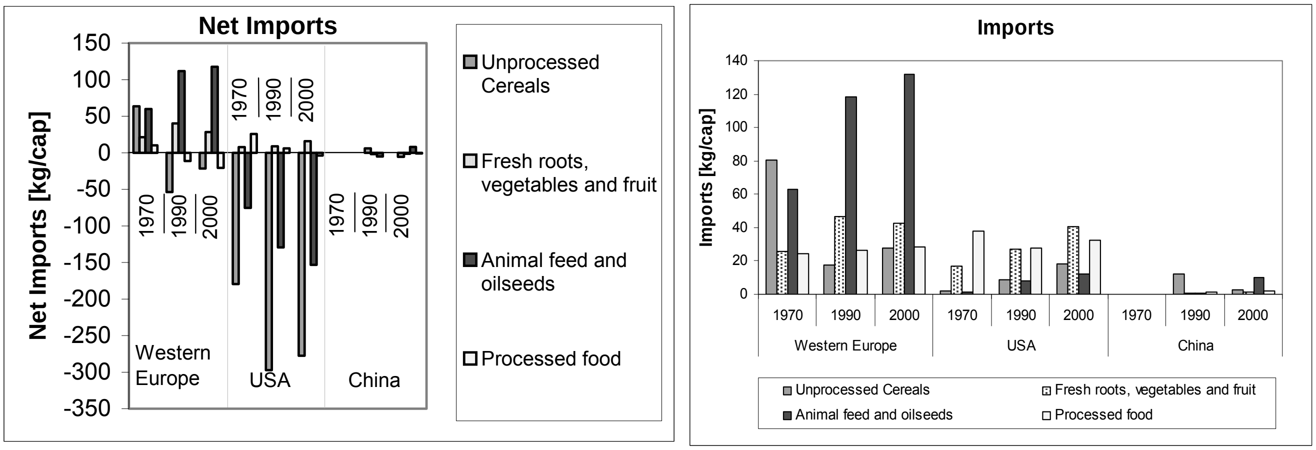

Figure 6: Trends in international trade. Source: Comtrade, 2007

The net trade balance of agricultural commodities, especially in the USA, is sufficiently large to necessitate a trade correction for a number of stages. For fertilizer manufacture, a simple method was used in which the domestic fertilizer consumption values were multiplied by a correction factor. This factor was equal to the sum of net imports and supply of food and feed divided by the supply. For example, Western Europe net imports, on a mass basis, was around 100 kg/cap in 2000, and its total supply of food and feed was near 2000 kg/cap, resulting in a correction factor of 1.05. The same correction factors were used to adjust for agricultural energy use and GHG emissions. For transport, more detailed data were available, allowing for a more sophisticated approach. Food was broken down by commodity group, and using average transport distances for these groups (see Section 3.4) together with the net imports of the same groups, a correction factor was calculated. This factor represents the tonne-kilometres from net imports plus domestic supply, divided by the domestic supply. Table 5 shows these correction factors (see Appendix 3 for the breakdown by commodity group).

Table 5: Import correction factors

	W Europe			USA			China		
	1970	1990	2000	1970	1990	2000	1970	1990	2000
Ag. and fert.	1.09	1.04	1.05	0.9	0.83	0.83	1	1.00	1.00
Transport	1.04	1.02	1.01	0.94	0.92	0.92	1	1.02	1.00

3.2 Agriculture

Here we examine two parts of the agricultural production system: animal feed and fertilizer consumption.

3.2.1 Animal feed

We used FAO food balances to determine the amount of animal feed produced, with some corrections for unreported feed. In general there is a lack of information on feed utilization,

[15] This is valid for oilseeds alone, not the combination of oilseeds and oilmeal (or animal feed and oil seeds shown in Figure 6), for which Western Europe still imports more than China.

which is also reflected in FAO statistics (Jacobs and Sumner, 2002), especially with respect to commodities produced and consumed within the same farm. Nonetheless, this data was considered the best available for the times and regions. A limitation of the food balances for feed is that they record only commodities which can be consumed by humans, thus the forages are not included. The focus on human consumption also results in a 'disappearance' of certain feed commodities as they move in the balances from one category to another. This is particularly important for oilseeds, where oil is extracted for human consumption and the remainder, oilmeal, is destined for animal feed. To correct for this apparent disappearance, the consumption of oilmeal is assumed to equal the amount of oilseeds going to manufacture minus the amount of oil produced, plus the net imports of oilmeal. Data for the latter were from Comtrade (2007).

Figure 7 shows the breakdown of animal feed commodities[16], neglecting the first category, forages, which accounts for roughly half of feed by weight. The remaining 50% still represents a major part of the food system, as it includes over 60% of all cereals produced in Western Europe and the USA. In China, cereals used for feed account for only 25% of domestic supply of all cereals. However this is growing rapidly (increasing from 18% in 1990 to 24% in 2000) (FAOSTAT, 2007). Excluding forages, cereals make up the bulk of animal feed on a kilogram basis (around half in Western Europe). However other commodities, specifically oilseeds, are essential to provide protein.

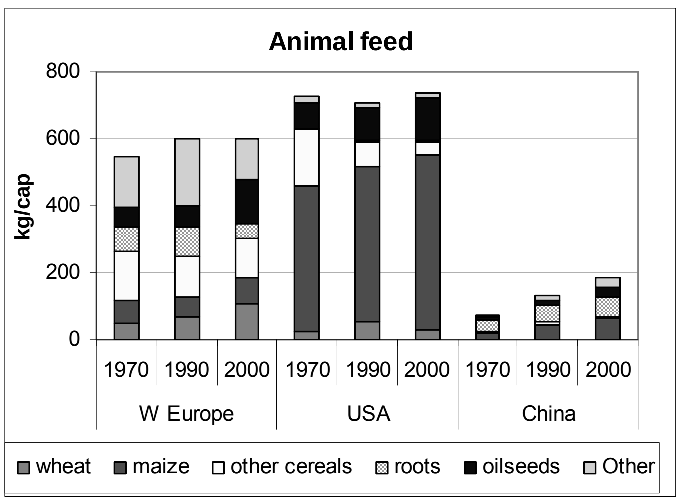

Figure 7: Consumption of animal feed. Source data: FAOSTAT and Comtrade

Comparing Figure 7 to the trends in meat consumption from Figure 1, it is evident that animal feed has not kept pace with the growth in meat[17]. Only oilseeds, the most significant of which is

[16] Animal feed can be divided into three broad categories (FEFAC, 2005): (1) Forages/roughages - including hay, straw, silage and pasture - which typically is produced and consumed within the same farm. This accounts for roughly 50% of feed by weight. (2) Cereals and other bulk feedstuffs without further processing. It can be either produced and consumed on the same farm - which accounts for slightly more than 10 % - or bought and sold on the market - which accounts for slightly less than 10%. (3)Industrial compound feed, which is sold on the market and accounts for around 30% of feed by weight.

[17] It would appear from Figure 7 that cereal use for feed has followed a downward trend in the USA between 1970 and 1990. However there are large year to year variations and the years around 1970 were unusually high. These variations can be attributed to changeable stock supply, planting rates and weather conditions. The trend for cereal use in feed in the USA, when considering all years between 1961 and 2003, can be more accurately described as level.

soy, has increased dramatically. To a large extent, soy has displaced other protein sources, especially in Europe, where food safety concerns have prompted bans on animal by-products[18].

The increasing demand for soy has been filled by rapid production increases, primarily in Brazil and Argentina (see Figure 8). This is especially important in terms of environmental impact because increased production has resulted from extension of agriculture, often encroaching upon forest (Hendry, 1995). Brazil and Argentina export around 60% of their production, mainly to Europe and China.

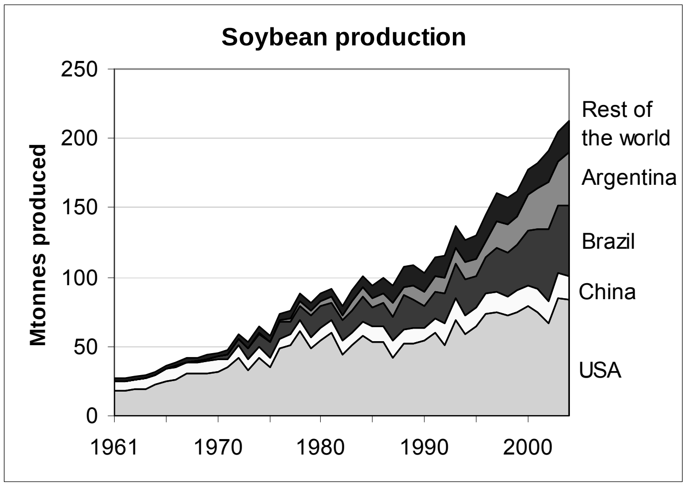

Figure 8: World production of soybeans. Source: FAOSTAT, 2007

Another factor that has affected feed components has been the trend towards more pig and poultry relative to bovine meat. Pig and poultry are monogastric, and are consequently fed higher quality materials - grains and oilmeal - than cattle. Pig diets typically consist of around 60-80% cereals and 10-20% oilmeal; chicken diets consist of 60% cereals and 20-30% oilmeal (Steinfeld, 2006). Another difference is the conversion rates - from kg of feed to kg meat – which for poultry is typically 2-4 compared to 7 for bovine meat (Rosengrant et al. 1997 from Steinfeld, 2006). This can help explain why feed production growth has not kept pace with meat production growth in any of the regions[19].

3.2.2 Fertilizer consumption

The application of manufactured fertilizers represents a major agricultural input, and has contributed greatly to the dramatic increase in yields since the 1960s (see Section 4.5). Three main nutrients are supplied by fertilizers: Nitrogen (expressed in terms of N), Phosphorous (expressed in terms of phosphate, i.e. P_2O_5), and Potassium - or potash - (expressed in terms of K_2O). Data on the consumption of fertilizers are available from the IFA (2007). These figures were adjusted based on the trade correction factors given in Table 5.

Figure 9 shows the trends in fertilizer consumption on a per capita basis (left side). The kilograms refer to the mass of the nutrients contained in the fertilizer, not the weight of the actual product. In Western Europe and the USA, per capita fertilizer use increased in the 1960s

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[18] This substitution is not clearly visible from Figure 7 because FAOSTAT data do not cover animal feed not fit for human consumption.

[19] This is not the only reason, as improved breeding techniques, varieties of feed and other technological improvements have also made a significant contribution.

and 70s, reaching a peak in the early to mid 1980s, and declining thereafter. In absolute terms, fertilizer application increased until the 1980s in both regions, but remained steady in the USA and decreased in Western Europe (from the mid 1980s-2005). The turnaround occurred as the available high yield cropland was fully exploited by the mid 1980s. In the USA this coincided with a peak in planted acreage (ERS, 2007b). More fertilizer input, yielding diminishing returns, became economically unattractive. Furthermore, as knowledge has advanced, farmers have increasingly matched specific crop needs with precise fertilizer application, eliminating excessive use (Muir, 2007). In contrast to Western Europe and the USA, China has not yet stabilized its fertilizer use (neither in per capita nor absolute terms), although the most rapid growth occurred during the 1970s and 1980s.

If expressed as fertilizer application per unit of land (right hand side of Figure 9), a particularly high value is observed for Western Europe in 1990. This was caused by the intensification of agriculture in the period 1970-1990, which was characterized by decreasing land use while fertilizer input remained high. The lower fertilizer use per hectare in Western Europe in 2000 is a consequence of lower fertilizer quantities compared to 1990, in combination with a somewhat larger agricultural area. In Western Europe, fertilizer use per hectare in the year 2000 was at a comparable level with the USA in the years 1990 and 2000. In China, the fertilizer application per unit of land has rapidly risen and has reached a value that is very close to the USA and Western Europe (Figure 9, right hand side).

Accompanying these changes in application rates has been a switch in the type of fertilizers used. In all regions, complex fertilizers (chemical mixtures of more than one nutrient) have declined in share, giving way to single nutrient fertilizers with higher nutrient content.[20] In the USA, this is driven by a consolidation of producers, geographically distant from consumers. Because of the transport distances, bulk materials with high nutrient content become more cost effective (Isherwood, 2000). (See Appendix 3 for more information about trends in specific fertilizers).

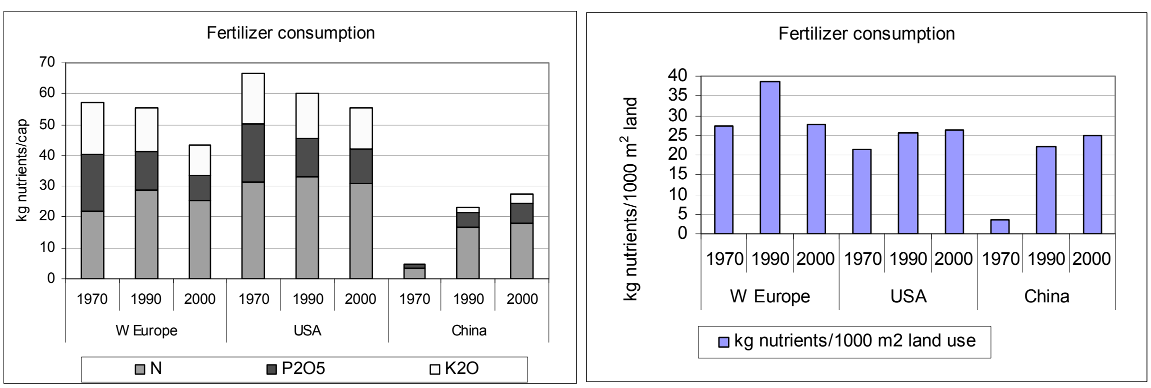

Figure 9: Trade adjusted fertilizer consumption. Source data: IFA, 2007; for land use data see Chapter 4.5

3.3 Packaging

Virtually all of the food which ends up in our homes is packaged in some form. However no data exists explicitly for the amount of packaging material used for food. To determine this, we first estimated the percentage of packaging material that is used in the food system for each of

[20] In Western Europe for example, in 1970 a complex of NPK (approximately 15-17% N) accounted for 9% of nitrogen fertilizers and calcium ammonium nitrate (CAN) (approximately 33-35% N) accounted for 31%. By 2000, the shares had change to 1% and 23% respectively, with much of the balance made up by urea (approximately 46% N). (Source: IFA, 2007 data with own calculations)

the major materials: paper, glass, metal and polymers. We then multiplied this by the total amount of packaging material consumed in all sectors.

Statistics for packaging material consumption are available from the respective environmental agencies - European Environment Agency (EC, 2001 and 2007) and US Environmental Protection Agency (EPA, 2006). The data for the USA were available from 1960 onwards, however for Western Europe they were only available from 1997 onwards. For values prior to then, the packaging materials were assumed to grow at the same rate as in the USA. For China, no packaging statistics were available, only municipal solid waste (MSW) flows by material for urban areas.

The allocation of packaging material to food differed between regions. For the USA packaging waste figures were detailed enough for most materials to be able to differentiate between food and non food related packaging (e.g., milk cartons could clearly be allocated to food). Where categories were ambiguous, rough estimates were made of the share for food packaging (e.g. 'other plastic containers)[21] (see Appendix 3). For Western Europe, literature and industry sources provided estimates per packaging material (EC, 2001; EUPC, 2007; ALUPRO, 2007). For China, because limited data were available, the share of food packaging material in the MSW stream was assumed to be the same as in the USA. The allocation factors are given in Table 6.

Table 6: Share of packaging materials allocated to food, by material.

	food packaging material / packaging material				food packaging material / MSW material
	W Europe	USA			China
	2000	1970	1990	2000	2000
Paper and Paperboard	0.40	0.28	0.33	0.32	0.24
Glass	0.95	0.93	0.93	0.94	0.35
Steel[22]	0.71	0.62	0.49	0.46	0.03
Aluminium	0.78	0.59	0.91	0.89	0.03
Polymers	0.54	0.50	0.46	0.46	0.36

Figure 10 shows the food packaging trends and material split. Plastics and paper have assumed a larger share since the 1970s, replacing glass; and aluminium replacing steel. This is not only the case in the USA. Although data is not available for all of Western Europe for the entire time period, examining the situation in UK reveals similar conclusions: plastics have grown from less than 8% of food packaging in 1984 to over 18% in 2004 (own calculation). Total per capita packaging consumption (by weight) has more or less stabilized, but this does not mean that the number of packaged goods has also stabilized. The material shift towards paper and plastics (which are much less dense than other packaging materials) and down-gauging hide the growth in packaging volume (see Appendix 3).

[21] The major unknown of the ambiguous categories was corrugated boxes, which accounted for around 75% of the paper packaging in the US in 2000. Corrugated boxes are often used for distribution of other packaged goods, thus good estimates for food are difficult. However, we used data from AICC (2007) to estimate 28% allocation to food (See Appendix 3).
[22] In the USA, steel beverage cans have been phased out, replaced by aluminium.

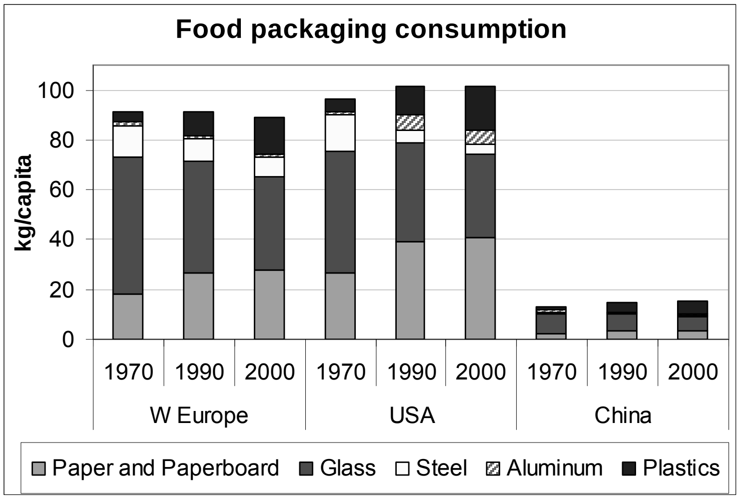

Figure 10: Food packaging trends, by material.

3.4 Transport

In all regions, the volume of domestic freight activity by mode (in tonne-kilometres) has been estimated by national statistical agencies (Eurostat, 2007; BLS, 2004 and 2007; NBSC, 2007) (see Appendix 3). Furthermore, in Western Europe and the USA, recent data are available which report the volume of freight activity differentiated by type of commodity for each mode (Eurostat, 2007; BLS, 2005). Table 7 shows the percentage of all commodities which are allocated to the food system for each mode. For China, this was not directly available. The only food category that was differentiated from the rest of freight was grains (cereals and oilseeds). To estimate the share of freight activity for food, by mode (e.g. food t-km by road / total t-km by road; which was available for the USA and Western Europe), two assumptions were made: (1) the modal breakdown of grains in 2000 (50% rail, 30% road and 20% water, from Huang, 2007) is assumed to extend to all food;[23] and (2) the total food tonne-km was assumed to comprise 25% of all freight traffic[24].

The food freight transport volume was calculated by multiplying these percentages by the total freight activity[25]. The latter is available for the entire time period; however time series data for the commodity breakdowns are scarce or unreliable[26]. Therefore, to estimate food transport volume over time, one further assumption was necessary: the percentage freight, by mode, allocated to food (i.e., the percentages shown in Table 7), was held constant over the time period.

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[23] According to FAPRI (2004, p.3) the breakdown the USA is as follows: 16.6% trucks, 44.4% rail and 27.4% water. We used the data from Huang for our calculations for all three regions. If reliable datasets were available for each region, this would allow to improve the quality of the results.

[24] Compared to Western Europe at 23% and the USA at 21% (own calculation from Eurostat (2007) and BLS (2005) data.

[25] The raw values for food tonne-km were not used directly because the commodity surveys from which they were determined did not cover 100% of freight transport. Thus the total of all commodities was slightly lower than the volume of freight transport estimated in other statistics.

[26] Freight activity data per mode by commodity is available for some European Union countries reaching back to 1982, however there were many gaps. For example, in 1982, complete data were available for only four European countries for rail transport, whereas in 2004 all were available. In the USA, a total of three commodity surveys were carried out in 1992, 1997 and 2002, however methodological changes make comparison difficult. For China only grain-transport was available.

In this way, the modal share of food followed the trends for all freight[27]. For example, in Western Europe in 2003, 24.1% of road freight volume was for transporting food according to Eurostat (2007). In 1970, we also allocated 24.1% of road transport to food.

Table 7: Percentage of food commodities transported (in tonne-km) out of all commodities transported for each mode of transport.

	W Europe	USA	China
Road	24.1%	22.9%	25.2%
Rail	5.9%	18.7%	22.9%
IWW	19.8%	50.4%	17.0% combined
Seas	assumed 19.8%	6.1%	

The domestic freight transport activity was corrected to obtain values for transport of food consumed that is consumed in the regions. As outlined in Section 3.1, the average transport length (in kilometres) by commodity group, shown in Table 8, was used to calculate the correction factors.

Table 8: Average transport length and modal split of food commodities. Source data: BLS, 2005 and Eurostat, 2007

	Average transport length[28] [km]		Modal split [%] (inland modes)					
	W. Europe	USA	W. Europe			USA		
			Road	Rail	Water	Road	Rail	Water
Cereals	128	758	76	17	7	9	58	33
Potatoes	250	872	99	1	0	82	18	0
Vegetables								
Fruit		926				100	0	0
Oilseeds	215	576	82	8	10	16	32	52
Live animals	97	417	97	3	0	100	0	0
Meat	171	775	96	3	1	98	2	0
Animal feed		361				62	36	2
Other prepared foods		589				75	24	1

Note: In China, the modal split of grain transportation was estimated to be 50% by rail (which averaged 1276 km (NBSC, 2007)), 30% by road, and 20% by water (Huang, 2007).

There is an additional major source of transport activity that has not yet been included, namely international maritime transport. The tonne-kilometres of this mode were calculated for each region and commodity by multiplying the tonnage imported from overseas[29] by the estimated shipping distance. To calculate the latter, first the share of imports that originated in various continents was determined from Comtrade data[30], along with estimated distance between the

[27] This does not mean that the modal breakdowns of all freight and food freight are the same, rather that the follow the same growth rates over time. (See Appendix 3 for a comparison of the modal breakdowns).

[28] Average length was calculated by dividing the amount of tonne-km by the tonnes hauled. This average is different than the average distance per shipment.

[29] It is necessary to distinguish overseas imports because often a large share of food imports originate in neighbouring countries and transported via inland modes (e.g. for the USA, the largest trading partner for cereals is Canada). However, as a consequence, the inland transport in the foreign country is excluded from the calculations (although it is included when it arrives in the destination country).

[30]The continents included were Asia, North Africa, Other Africa, North America, Central America, South America, Western Europe and Other Europe. Imports from the respective continent in Western Europe, the USA and China were assumed to be transported via inland modes.

origin and destination (see Appendix 3). Only included are those commodity groups where imports have been greater than 10 kg/cap.

Figure 11 shows the trends in food transport volume, broken down by mode. Domestic food transport activity in the USA has consistently been about 2 ktonne-km/cap greater than in Western Europe (on the order of 2 – 4 times greater), and 2.5 – 3 ktonne-km/cap greater than in China. Including international maritime transport greatly reduces the ratio for Western Europe. Differences between modes and distance travelled in Western Europe and the USA can be attributed to geography. For all domestic freight transport, the USA averages a distance of 3 times greater than Western Europe. These longer transport distances (and a homogenous rail network) in the USA favour rail over truck.

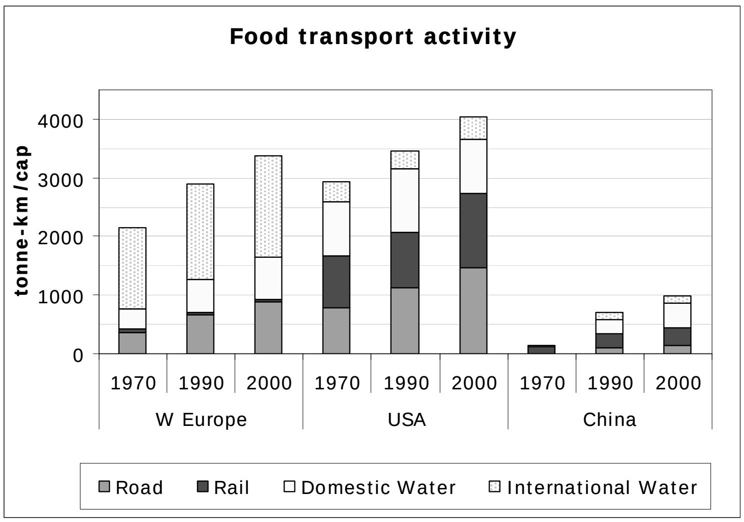

Figure 11: Historic food transport activity, in tonne-kilometres per capita

Food freight activity increases in Western Europe and the USA are due in large part to increases in transport distances. Driving these changes has been the opening up of neighbouring markets, especially in Europe, where the formation of a common marketplace and free flow of goods has greatly increased transport distances. Furthermore, perishable food items such as fruits and vegetables, and meat can more frequently be transported long distances without quality loss. This has been made possible by transportation technology improvements - especially refrigerated containers with sophisticated climate monitoring systems and containerization in general, which has resulted in faster handling and made intermodalisation possible (Coyle et al., 2001 in Regmi, 2001). The movement towards concentration in manufacturing and distribution has also been cited as a contributing factor, because fewer processors and warehouses implies longer distance between them (Garnett, 2003). Modal shifts towards trucks can be explained by logistic developments which emphasize flexibility and just-in-time deliveries (Garnett, 2003). Road transport is better suited for these shipments.

4. Environmental Impacts

In this section we will assess the environmental impacts which occur in the food systems. We limit the analysis to three main impact categories: energy use, greenhouse gas emissions and land use. The results will provide information regarding (1) quantification of the impact and the variation across time and between regions, (2) the relative importance of each commodity, (3) the relative importance of each stage in the life cycle, and (4) the significance of consumption pattern changes.

4.1 Method for determining environmental impacts

In order to determine energy use and greenhouse gas emissions, we employed two separate analyses: a food product analysis and a system level analysis. The food product analysis consists of determining the impact per kilogramme for 19 major food products. This was done for Western Europe in 2000. These values were multiplied by the availability (see Section 2.2) in order to approximate the per capita energy and greenhouse gas emissions.[31] We also applied the specific energy/emissions values for Western Europe in 2000 to consumption patterns over time and across regions, to estimate the expected difference in environmental impact solely based on differences in consumption. This was later compared to the results from the system level analysis.

For the system level analysis, each food stage (i.e. agriculture, fertilizer productions, transport, food processing and packaging) was examined individually for all food products combined. This included all regions and time periods. The energy use and emissions was determined for each stage either from sectoral energy statistics or from the results of Section 3 along with corresponding data on energy use and emissions or intensity. For Western Europe in 2000, the per capita energy and GHG emissions at each stage were averaged with those from the food product analysis to obtain a best estimate. For other years and regions, we multiplied this best estimate by the relative difference of the regions/times to Western Europe in 2000, as determined from the system level analysis.

In order to determine land use the following procedure was used. The specific land use requirement (m^2/kg of primary product) was calculated for each primary crop commodity in the three regions, using the inverse of yields[32] as reported by FAOSTAT (2007). The specific land use requirements were multiplied by the amount of crops initiated for food consumption[33], determined from FAO FBS. Similarly, the total land use requirements for animal products was determined by multiplying the specific land use requirement for each feed crop by the amount initiated for feed consumption. This does not include a pasture land for grazing, which is excluded from this study. Seed use and waste was allocated proportionately on a weight basis between food, feed and other uses. For categories that were not in primary form (i.e., vegetable

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[31] For products not explicitly included, the following procedure was used to estimate energy/emission factors: If the commodity group was included but not the product (e.g. cereals other than wheat bread, pasta and rice), the weighted average on a mass basis of specific energy/emissions values for products in that commodity group was used. If the entire commodity group was left out (e.g. alcoholic beverages) a weighted average of all groups was used.

[32] As a consequence, the land use calculated refers to harvested area rather than planted area.

[33] This is different from the amount that is produced because some are used in other industries, e.g. starch is used in the paper industry and vegetable oil can be used as fuels.

oils and sweetener) they were converted back into primary form, using mass conversion factors from FAO (1994). Co-products were allocated between food and feed on an economic basis[34]. It should be noted that, by multiplying values representing food and feed consumption with specific land use requirements, the *entire* consumption within a region is assumed to be provided by production within this region.

4.2 Food product analysis

Various sources were combined to determine the (non-renewable) primary energy use per kilogramme of product (MJ/kg) and GHG emissions per kilogramme of product ($kgCO_{2-eq}/kg$) in the life-cycle of the food products examined in Section 2.2. The sources are described in Table 9, along with the food products for which they were used and the adjustments that were necessary in order to make the values comparable. In general, the energy use at each stage was averaged among available sources for each food product. For some products - namely processed potatoes, fresh fruits and fresh vegetables - the information was not sufficient, so data from Carlsson-Kanyama (2003) were used to adjust similar products. Specific GHG emissions were determined in the same basic manner, by averaging the available values at each stage. However for some sources only energy was available, in which case emission factors (per unit of energy) for each stage, as calculated in Section 4.3, were multiplied by the energy use. (See Appendix 4 for more details.)

Table 9: Sources used for constructing specific energy use and GHG emission f actors

Source	Food products	Stages	Impact category	Adjustments
LCA food database (Nielsen et al, 2003)	bread, potatoes, sugar, oil, milk, cheese, beef, pork, chicken, milk, cheese	cradle to factory gate	energy and GHG	Data in its original state refer to the marginal impact[35]. Here we are interested in the average impact, so to adjust, we recalculated in SIMAPRO by excluding all avoided products. (Additional information on the assumptions, inputs and results can be found in the Appendix.)
Carlsson-Kanyama, 2001 and 1998	pasta, rice, potatoes	cradle to factory gate	energy and GHG	The energy use due to conversion of fuel to electricity was excluded[36], so a rough estimate of 1.3 joule primary per 1 joule final was used[37], Also CO_2 equivalents which were calculated on a 20 year time span, which results in higher values for methane emissions. This is relevant for rice and was adjusted. See Appendix for details.
Foster, 2006	bread, beef, pork, milk, cheese	cradle to factory gate	energy and GHG	For pork, the agriculture and fertilizer stage as reported included transport and processing of animal feed. The contribution of these stages was determined for the LCA food data, and subtracted from the Foster values.

[34] Allocation on an economic basis was carried out where data was available; elsewhere the allocation was based on mass.
[35] This includes assumptions that consumption of one additional product induces another product to be avoided. For example consumption of one kg of inexpensive beef triggers an avoided kg of inexpensive pork.
[36] Although transmission losses and conversion from fuel to heat was included.
[37] This is based on an estimate of 20% electricity use (out of total final energy) with a conversion efficiency of 40%. In Western Europe in 2000 14% of final energy was electricity in the agriculture sector and 30% in food processing (calculated from IEA, 2007 data)

Ramirez, 2005	pasta, frozen vegetables, fruit juice, sugar, oil, beef, pork, chicken, milk, cheese, highly processed meat	processing only	energy only	In some cases primary energy was not given as such but split into carriers. Electricity was converted to primary energy assuming a conversion efficiency of 40%.
Wiegmann et al., 2005	bread, canned vegetables	processing only	energy only	In some cases only final energy was given, in which case a rough estimate of 1.45 joules primary per 1 joule final was used[38], in other cases electricity was given, which was converted to primary energy by assuming a conversion efficiency of 40%.
Williams et al., 2005	beef, pork, chicken	agriculture/ fertilizers only	energy and GHG	The agriculture and fertilizer stage as reported included transport and processing of animal feed. The contribution of these stages was determined for the LCA food data, and subtracted from the Williams et al. values.
UNEP, 2001	milk	processing only	energy only	Electricity was converted to primary energy assuming a conversion efficiency of 40%.
Carlsson-Kanyama, 2003	processed potatoes, fresh vegetables, fresh fruits	cradle to factory gate	energy only	Used for scaling – Data used were adjusted to exclude differences in cooking and household storage.

Table 10 gives the primary energy use and emissions for each of the 18 major food products representing the production system in Western Europe in 2000. Table 11 shows the resulting energy and emissions per capita.

Table 10: Primary energy and emissions of each food product[39]

		Primary energy $MJ/kg_{product}$	GHG emissions $kgCO_2/kg_{product}$
Cereals	Wheat Bread	8.1	0.97
	Wheat pasta	10.9	1.53
	Rice	11.4	3.5
Roots	Fresh potatoes	1.9	0.19
	(Frozen) processed potatoes	13.7	1.3
Vegetables	All Fresh vegetables	3.1	0.3
	All Frozen vegetables	9.9	0.7
	All Canned vegetables	8.4	0.6
Fruits	All Fresh fruits	4.9	0.44
	Fruit juice	8	0.66
Sugar	Sugar	13.2	1.23
Oil	Oil	7.2	1.26
Animal products	Beef	41.7	25.23
	Pork	20.8	4.92
	Chicken	16.8	4.08
	Milk	4.3	1.12
	Cheese	40.0	11.74
	Highly processed meat	+3.4	+0.3

[38] This is based on an estimate of 30% electricity use (out of total final energy) in food processing, based on calculations from IEA (2007), with a conversion efficiency of 40%.
[39] This table refers to the impact per kilogramme of final product (at the household level), as opposed to per kilogramme of primary product. There is often a change in mass occurring from primary to final product. This, along with extra processing energy, accounts for much of the difference between minimally processed foods and highly processed foods. See Appendix 4 for the mass conversions.

Table 11: Availability, energy and GHG emissions for W Europe 2000, based on product analysis.

	Availability		Energy use	GHG emissions
	kg/(cap·yr)	kcal/(cap·day)	GJ/(cap·yr)	tonneCO_2/(cap·yr)
Cereals	115	872	0.96	0.15
Starchy roots	80	143	0.24	0.02
Vegetables	128	87	0.48	0.04
Fruits	114	132	0.58	0.05
Sugar/sweetener	39	376	0.52	0.05
Oil	20	489	0.14	0.03
Meat	90	428	2.39	0.86
Milk	247	326	1.31	0.34
Other	190	643	1.51	0.35
Total	1024	3496	8.13	1.90

note: total may not sum due to rounding

The difference in relative impact can be seen clearly from these tables. Meat and milk products are by far the largest contributors to energy use and especially GHG emissions, contributing 63% to the latter. Of these, beef is the most significant, more than double the energy use and five times the GHG emissions per kilogramme of other meat. Less extreme, but still important, sugar and sweeteners use a large amount of energy, especially considering their relatively low availability (on a mass basis). Also rice, because of methane that is produced during the agriculture stage, results in high emissions per kilogramme.

The implications are obvious: regions with high availability of these high impact foods can be expected to use more energy and emit more greenhouse gases. But to what extent? And do these expectations correspond to actual impact? We examine here the expectations, before returning later to the actual impacts. As shown in Figure 12, we see how the varying consumption patterns are expected to affect energy and GHG emissions. Because the same specific energy/emissions values were used in the calculations, and because these were based on conditions typical for Western Europe (around 2000), the figures give us an impression of the energy and emissions that would occur if the consumption patterns of the past or those in other regions were to be adopted in Western Europe.

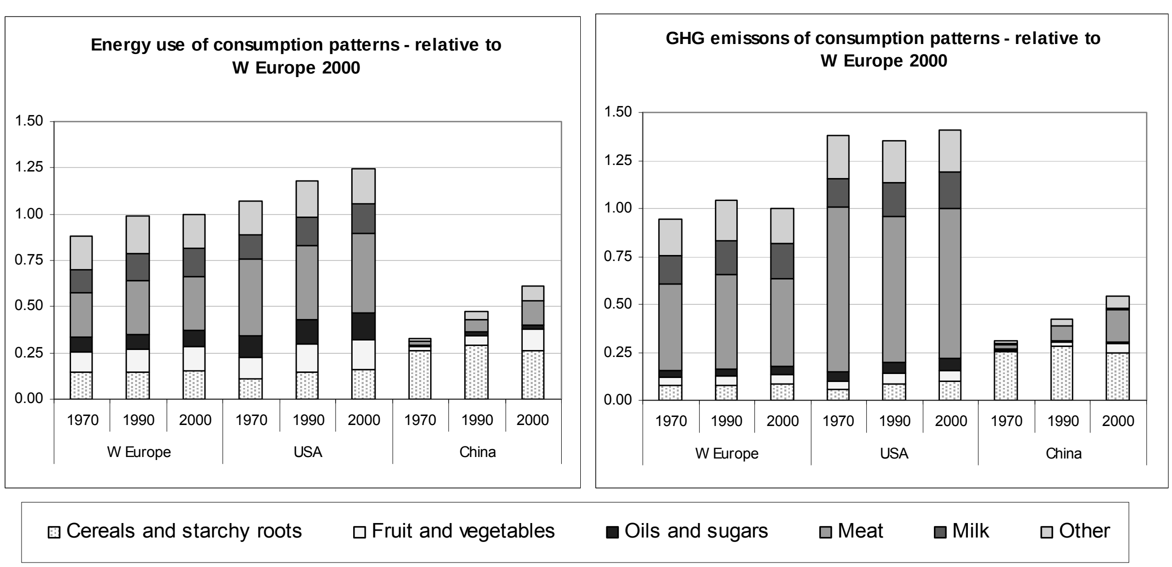

Figure 12: Relative difference in energy and GHG emissions based only on differences in availability.

4.3 System level analysis

The system level analysis consisted of calculating energy and GHG emissions for each stage of food production, for the three regions and over time. The sources and methods used vary from stage to stage. In the case of agriculture and processing, internationally comparable data was available from the IEA energy balances for the domestic energy use at that stage. In the case of transport, IEA energy balances contain overall transport energy use, which includes freight as well as passenger transport. This could not be used directly, so instead the structural activity (tonne-km of food transport, by mode, as calculated in Section 3.4) was multiplied by the energy use per tonne-km of each mode. The energy use of passenger transport and non-food freight transport was also calculated so that the values could be calibrated to IEA values where possible (see Appendix 5). For fertilizers and packaging, the structural activity (kg of fertilizer consumed, by type, and kg of food packaging, by material, as calculated in Section 3.2.2 and 3.3 respectively) was multiplied by primary energy requirement to produce that fertilizer or packaging material.

GHG emissions due to energy use were determined by multiplying default emission factors by the type of fuel used, if known. Table 12 lists the default emission factors, along with the variable factors for electricity[40]. For fertilizers and packaging, the fuel mix was not explicitly available, so instead we used specific GHG emission factors found in the literature (see Sections 4.3.1.1 and 4.3.4).

Table 12: Emission factors. Source: IPCC, 2006 and data from IEA, 2007

Fuel combustion	$kgCO_2$ / GJ_{LHV}	Electricity		$kgCO_2$/ MWh
		W Europe	1970	607
All regions			1990	407
Brown coal	101		2000	328
gasoline	69	USA	1970	666
diesel fuel	74		1990	597
heavy fuel oil	77		2000	596
natural gas	56	China	1970	941
			1990	868
			2000	839

In Sections 4.3.1 through 4.3.5, more detail is given about the calculations at each stage.

4.3.1 Agriculture

The IEA data are in general comparable, however some adjustments were needed to remedy missing information. Data from the USA required an estimation of electricity use because the electricity for agriculture was reported together with households. We assumed that the USA agriculture would use the same share of total energy for electricity as Western Europe[41]. Also, China data only went back to 1980. For each fuel, the energy use was extrapolated linearly from 1980 to 1970. Another data issue arose because the statistics for all regions represent the

[40] The factors for electricity production were calculated based on IEA (2007) balances for main activity electricity plants. The fuels used in electricity conversion processes were multiplied by their emission factors and divided by the electrical output.
[41] The share of final energy in the form of electricity was around 10% in the 1960s, increasing slowly to over 15% by the 1990s and over 20% by 2000.

agricultural sector as a whole, which includes production of goods other than food, e.g. forestry for paper and pulp. However, food production is assumed to be the largest use by far thus the impact of other uses should have a marginal impact on the relative difference in energy use between the regions and over time. Electricity was converted to primary energy using the respective averages for conversion efficiencies of main activity electricity plants by year and region, calculated from the IEA energy balances[42].

In contrast to most other sectors where fossil fuel combustion is the primary source of greenhouse gas emissions, agriculture emissions come from a variety of sources. The four other main sources in agriculture are listed below:

Enteric fermentation: This refers to the process whereby microbes produce methane via fermentation in the digestive track of animals, breaking down coarse plant material which otherwise could not be digested. This process is especially important in ruminant animals (e.g. cattle); non-ruminant animals such as pigs and poultry produce significantly less methane from enteric fermentation (EPA, 2007). The amount of enteric fermentation in ruminants is primarily dependent on the amount of feed intake – related to its size, growth rate and production (of milk, for example) – and to a lesser extent on the composition of feed (IPCC, 2006).

Manure management: Manure is a source of both CH_4 and N_2O emissions. The former is produced when manure decomposes under anaerobic conditions; the latter occurs as the nitrogen contained in the manure undergoes combined nitrification and denitrification[43]. The amount of emissions depends on the animal types, storage conditions, and other variables such as temperature. Cattle and pig manure are significant emission sources (IPCC, 2006).

Soil management: Direct emissions from soil management occur when excess nitrogen is available in the soil, increasing nitrification and denitrification rates and thereby N_2O emissions. Excess Nitrogen is frequently provided by manufactured and organic fertilizer application; however crop residues and land use changes also play a role (IPCC, 2006).

Rice cultivation: Methane is produced from anaerobic fermentation in flooded rice fields and is transported through the rice plants and released to the atmosphere. The amount of methane depends on the length of the growing season, the water regime and the soil type (IPCC, 2006).

For these non-energy sources of emissions, we made use of GHG inventories compiled by the national governments and reported as part of their obligations under the UNFCCC (EEA, 2007; EPA, 2007; ONCCCC, 2007). For Western Europe and the USA, emissions have been reported from 1990 on; for China they have been reported only for 1994. To estimate the emissions in other years, we first determined the main physical flows from which emissions arise – number of cattle head for enteric fermentation, number of cattle head equivalent[44] for manure management, kilogramme of Nitrogen fertilizer consumed for soil management, and kilogramme of rice cultivated for rice cultivation – then we divided the emissions in known

[42] To calculate the average efficiency, the amount electricity generated by main activity electricity plants (in PJ) was divided by the amount of fuel used those plants (in PJ). Implicit in these calculations are the assumptions made by the IEA, for example that nuclear plants operate at an efficiency of 33%. See IEA (2007) for more detail on the assumptions used.

[43] Nitrification is the process by which ammonium (NH_4) is converted to nitrate (NO_3); Denitrification is the process by which nitrate is converted to gaseous forms of nitrogen such as dinitrogen oxide (N_2O).

[44] Cattle and pigs contribute significantly to emissions from this source, but in different proportions.

years by these physical flows, and finally assumed the emissions in unknown years changed proportionally with the physical flows (see Table 13).

Table 13: Factors used to determine the GHG emissions from various agricultural sources. Source data: EEC, 2007; EPA, 2007; ONCCC, 2007; FAOSTAT, 2007; IFA, 2007

	W Europe			USA			China			
	1970	**1990**	**2000**	**1970**	**1990**	**2000**	**1970**	**1990**	**1994**	**2000**
Enteric fermentation [tCO_2 eq./head cattle]	1.6	1.6	1.6	1.2	1.2	1.2	2.4	2.4	2.4	2.4
Manure management [tCO_2 eq./head cattle-eq]	0.37	0.37	0.37	0.24	0.22	0.26	0.15	0.15	0.15	0.15
Soil management [$kgCO_2$ eq./kgN fertilizer]	20	20	21	36	36	36	12	12	12	12
Rice cultivation [$kgCO_2$ eq./kg rice cultivated]	0.98	1.03	0.94	0.93	1.00	0.87	0.68	0.68	0.68	0.68

note: Shaded cells indicate that emission data was unavailable for those years. These values were estimated based on average of years for which data was available (non-shaded cells).

The domestic energy use and greenhouse gas emissions values were then multiplied by the trade correction factors listed in Table 5.

4.3.1.1 Fertilizers

Primary energy and specific GHG emissions were taken from literature sources: Kongshaug (1998), which reported averages for West Europe at the time of publication, was used for Western Europe and the USA in 2000; Ramirez (2005), which reported world averages, was used for China in 2000. Ramirez also examined the efficiency improvement over time. The relative changes were used to scale the 2000 values. The results are shown in Table 14 and 15. These factors were multiplied by the consumption of the fertilizers, reported by the IFA (2007), to obtain primary energy and GHG emissions in the regions over time.

Table 14: Primary energy requirement for fertilizers

$MJ_{primary}/kg_{nutrient}$		W Europe and USA			China		
		1970	**1990**	**2000**	**1970**	**1990**	**2000**
N only	Ammonium sulphate	36.7	31.3	28.6	54	46	42
	Urea	68.2	54.8	48.0	71	57	50
	Ammonium nitrate	69.9	46.6	38.8	72	48	40
	Calcium amm. nitrate	72.7	47.3	40.0	80	52	44
	Ammonia direct	50.2	42.7	39.0	54	46	42
	Nitrogen solutions	50.9	43.4	39.6	54	46	42
P only	Single Super Phosphate	3.1	1.8	1.4	15	9	7
	Triple Super Phosphate	10.4	6.3	5.2	20	12	10
K only	Potassium chloride	10.7	9.2	8.3	6.4	5.5	5
	Potassium sulphate	3.6	3.1	2.8	6.4	5.5	5
Complex	AP (P_2O_5)	20.4	12.4	10.2	38	23	19
	PK (P_2O_5)	24.8	16.7	14.1	58	39	33
	NPK (N)	85.5	60.2	50.7	135	95	80

Table 15: Specific GHG emission for fertilizers

$kgCO_{2eq}/ kg_{nutrient}$		W Europe and USA			China		
		1970	1990	2000	1970	1990	2000
N only	Ammonium sulphate	2.08	1.77	1.62	3.06	2.61	2.38
	Urea	1.88	1.51	1.33	1.96	1.57	1.38
	Ammonium nitrate	12.25	8.17	6.81	12.63	8.42	7.02
	Calcium amm. nitrate	12.49	8.12	6.87	13.74	8.93	7.55
	Ammonia direct	2.99	2.55	2.33	3.22	2.75	2.51
	Nitrogen solutions	8.79	7.48	6.83	9.32	7.94	7.25
P only	Single Super Phosphate	0.20	0.12	0.10	1.00	0.60	0.47
	Triple Super Phosphate	0.71	0.43	0.35	1.36	0.82	0.68
K only	Potassium chloride	0.73	0.62	0.57	0.44	0.37	0.34
	Potassium sulphate	0.26	0.22	0.20	0.46	0.39	0.36
Complex	AP (P_2O_5)	1.22	0.74	0.61	2.28	1.38	1.14
	PK (P_2O_5)	1.60	1.07	0.91	3.74	2.52	2.13
	NPK (N)	7.12	5.01	4.22	11.24	7.91	6.66

4.3.2 Processing

IEA data for processing was used, with the following adjustments. Values for 1972 were used in Western Europe and 1971 in the USA for 1970 because of missing data before those years. No adjustments were made for trade because net trade of processed foods are close to balanced in all regions. Similar to the agricultural sector, processing contained some activity outside the food system. However this was assumed to be negligible.

4.3.3 Transport

In order to calculate the transport energy use from food, we multiply the food activity (in tonne-km, calculated in Section 3.4) by the average specific energy use[45] (in MJ/tonne-km), by mode. Specific energy use values were obtained from the Odyssee database[46] (2001) for Western Europe, EERE (2007) for the USA, and Skeer and Wang[47] (2007) for China. For the USA and Western Europe, the specific energy use factors were then calibrated with IEA transport energy use data[48] (see Appendix 5). The specific energy use was not available from these sources for international shipments, so an estimation was used from Breugham et al. (2004).

Table 16 gives the specific energy use values that were used in this study. GHG emissions were calculated by multiplying energy use by fuel[49] with the emission factors from Table 12.

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[45] Although the specific energy use can vary widely depending on the commodity transported, a study by Vanek and Morlok (1998) of US transport revealed that the specific energy use of food and agricultural commodities are relatively close to the average compared with other commodity groups (within 45%). However the specific energy use of food products transported by rail increased significantly from 1972 to 1993, despite a declining average value.
[46] Odyssee data were available from 1980 onwards. The value for 1970 was assumed to be equal to 1980 (based on level trend). However the calibration reduced this by 13%.
[47] Estimates before 1990 were not available, so the value for 1970 was assumed to be equal to 1990.
[48] The calibration had a negligible effect on total energy use, except for 1970 in Western Europe. For China calibration was not possible because of lack of data.
[49] The share of electricity for rail food transport was assumed to equal the share for all of rail transport, as reported by IEA (2007) energy balances.

Table 16: Specific energy use for domestic freight transport [MJ/tonne-km][50]

	W Europe			USA			China		
	1970	1990	2000	1970	1990	2000	1970	1990	2000
Road	2.6	3.0	2.8	2.1	2.5	2.4	2.9	2.9	4.0
Rail	0.8	0.5	0.6	0.5	0.3	0.2	0.5	0.5	0.3
Domestic Water[1]	0.4	0.3	0.3	0.4	0.3	0.3	0.4	0.4	0.2
International Water	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

notes: 1. The domestic water specific energy is a mix of inland shipping and domestic marine shipping.

4.3.4 Packaging

Packaging was not included in the system boundaries of the food product analysis, so in addition to the relative values over time and across regions, the raw values from this calculation were used for Western Europe in 2000. The primary energy requirement and specific emissions factor of the various packaging materials were multiplied by the amount of food packaging material consumed (see Section 3.3). The primary energy and specific emission factors include the processes up to and including the raw materials manufacturing, which represents the main portion of life cycle energy use/emissions. In the case of polymers, the energy and emissions from the product processing stage was deemed too significant to neglect, thus an additional 25 MJ/kg and 1.5 $kgCO_{2-eq}$/kg were added. See Table 17 for the values used[51]. The waste management stage has been excluded, which could have a substantial impact in lowering the energy requirement. (See Appendix 5 for more information)

Table 17: Primary energy requirement and specific emissions factor for packaging materials, system "cradle-to-factory gate". Source: CleanTech

Packaging type	**Primary energy requirement [MJ/kg]**	**Specific GHG emissions [$kgCO_2$-eq./kg]**
Paper (board)	15	1.0
Glass (container glass)	8	0.6
Steel (50-50 mix of primary and secondary)	15.5	1.2
Aluminium (50-50 mix of primary and secondary)	104	9.0
Polymers (generic polymer production chain)	88	2.9

4.3.5 Regional and temporal differences from the food system analysis

The results of the system level analysis, relative to the energy use / GHG emission at each stage for Western Europe in 2000, are presented in Table 18. Growth rates in transport, packaging and processing are strong throughout all regions, whereas agriculture and fertilizers have grown slowly or declined in Western Europe and the USA.

[50] The values given in the table are within the range given in other published sources, e.g. van Essen et al, 2003 and Bos, 1998.
[51] Comparing the table values with a packaging LCA study by the Danish Environmental Protection Agency (2001) shows agreement except for paper (+50%) and steel (+ 100%) after adjusting for waste treatment.

Table 18: Impact during stages of the food life cycle relative to Western Europe 2000

		W Europe 1970	W Europe 1990	W Europe 2000	USA 1970	USA 1990	USA 2000	China 1970	China 1990	China 2000
Energy use	Transport	0.52	0.84	1.00	0.81	1.14	1.35	0.03	0.17	0.26
	Packaging	0.52	0.73	1.00	0.65	1.13	1.34	0.14	0.22	0.30
	Agric.+Fert.	0.90	1.07	1.00	1.36	1.17	1.09	0.28	0.50	0.55
	Processing	0.76	0.91	1.00	0.86	1.20	1.38	0.20	0.20	0.16
GHG emissions	Transport	0.53	0.84	1.00	0.82	1.15	1.36	0.03	0.17	0.26
	Packaging	0.91	0.89	1.00	1.05	1.32	1.36	0.16	0.19	0.22
	Agric.+Fert	1.06	1.11	1.00	1.75	1.53	1.42	0.30	0.48	0.51
	Processing	1.16	1.05	1.00	1.26	1.63	1.75	0.38	0.38	0.30

4.4 Energy and GHG emissions

The values in Table 18 can then be multiplied by the reference value – Western Europe, 2000 – to obtain a best estimate of the total of the energy use and greenhouse gas emissions across regions and time. Calculations for Western Europe in 2000 were made in both the system level analysis and in the food product analysis, the best estimate being the average at each stage (shown in Table 19). The agriculture and fertilizer stages, which contribute by far the most to overall GHG emissions, shows close correlation between the two methods. However, transport and processing, especially for energy use, show considerable variation.

Table 19: Energy and GHG emissions results for W Europe 2000, from food product analysis and system level analysis.

	System level analysis	Product analysis	**Average**
Energy [$MJ_{primary}$/cap]			
transport	3.02	1.5	**2.3**
processing	4.0	1.9	**2.9**
agriculture and fertilizers	4.2	4.1	**4.2**
GHG [tonne CO_{2-eq}/cap]			
transport	0.22	0.12	**0.17**
processing	0.20	0.16	**0.18**
agriculture and fertilizers	1.37	1.56	**1.46**

The results of both the energy and CO_2 analyses are shown in Figure 13. In comparing these results with the expectations from the food product analysis, we see that that the regional variation can be rather accurately predicted from differences in consumption patterns alone. For example the total energy use of the USA in 2000 according to Figure 13 is very near 1.25 times Western Europe in 2000, as predicted in Figure 12. However temporal variations are underestimated by examining consumption changes alone. Also, the comparison of Western Europe with China does not fit as well as with the USA. An explanation for this lies in that the food product analysis does not take into account differences in efficiency, which for the USA and Western Europe are presumably small for a given time period.

Nonetheless the results suggest that reductions in high impact foods can have a strong impact on the total energy use. Bovine meat, which was previously identified as the most intensive of the major products, would therefore be a prime candidate. The following exercise illustrates the impact it could have. If 9 kg/cap of bovine meat were avoided in Western Europe in 2000 (representing 10% of meat availability), with those 9kg/cap spread evenly among other commodities, the energy use decreases by 4.8% and GHG emissions by 14.6%. Furthermore, if the 9 kg/cap of avoided beef was picked up by other meat products (instead of all other products, as calculated previously), the reductions would still be significant: 3.3% for energy and 12.9% for GHG emissions.

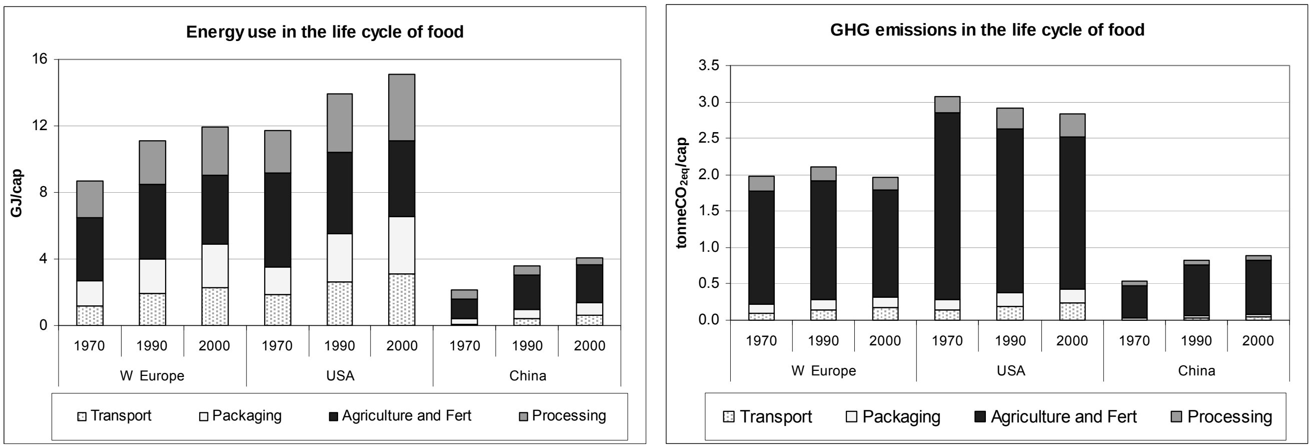

Figure 13: Energy use and GHG emissions in the food system, by stage

4.5 Land use

Great improvements have been made in all regions in the efficiency of land use across nearly all crops (see Table 20). As a result, the amount of land necessary to provide an adequate supply of food has declined. In Western Europe and the USA, shifts towards more intensive consumption patterns and growing populations have roughly balanced out those land efficiency gains. The same cannot be said of China, where the rapid increase in meat availability has led to expanding land use for livestock feed, and consequently increasing absolute (non-grazing) land use (see Figure 14). China has used a relatively large amount of land per capita (in 2000 it was only 30% less than Western Europe), despite consuming much less food per capita, specifically meat (50% less by weight in 2000). This is mainly due to the low yields, which are typically more than 20% lower in China than in Western Europe or the USA (see Table 20 for the inverse of yields).

These results refer to non-grazing land use. If grazing were included, the total land use figures would be much higher, especially in the USA. However, the amount of pasture land available differs substantially across regions, leading to different intensities of use. For this reason, direct comparison of grazing land use is problematic and has been excluded here.

Table 20: Land requirements [m^2/kg] (inverse of yield). Source data: FAOSTAT 2007

	W Europe			USA			China		
	1970	1990	2000	1970	1990	2000	1970	1990	2000
Cereals	3.6	2.1	1.7	3.2	2.1	1.7	4.7	2.3	2.1
Starchy roots	0.5	0.4	0.3	0.4	0.3	0.2	0.8	0.7	0.6
Vegetables	0.6	0.4	0.4	0.7	0.4	0.4	0.7	0.6	0.5
Fruit	1.1	1.1	0.9	0.6	0.5	0.4	2.4	2.5	1.4
Sugar crops	0.3	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2
Oilseeds	5.7	5.2	4.7	6.9	5.2	4.6	11.3	7.5	6.2

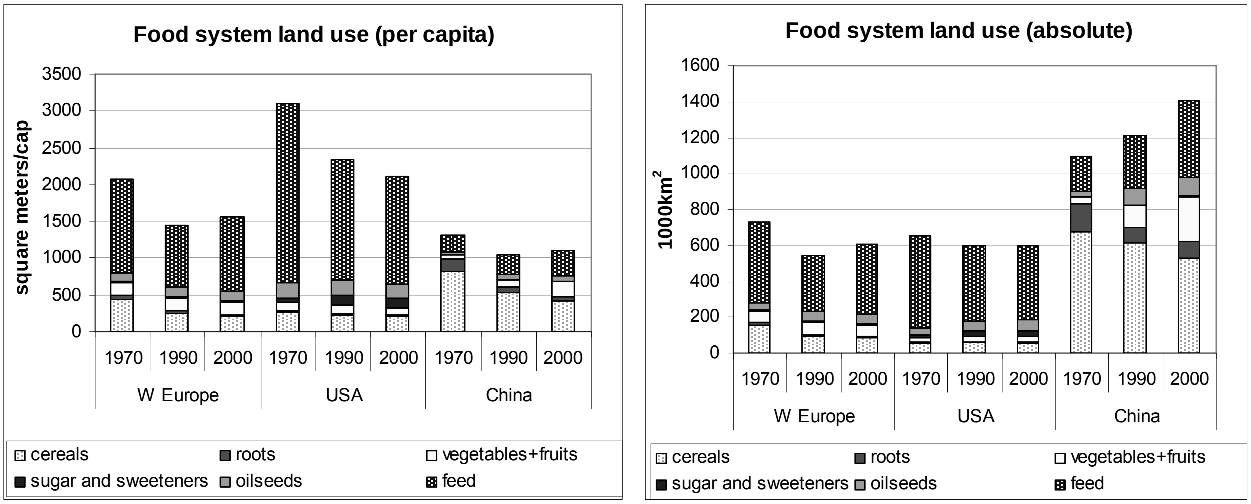

Figure 14: Trends in land use in the food system (own calculations)

The extensification of land use for production of feed has in large part occurred abroad, notably through oilseeds grown in the Americas (see Table 21 and Section 3.2.1). Both China and Western Europe have rapidly increased in this regard.

Table 21: Land use abroad for oilseed production (own calculations)

	W Europe			USA			China		
	1970	1990	2000	1970	1990	2000	1970	1990	2000
Per cap. land use[m^2/cap]	42	42	83	-70	-74	-108	0	-3	10
Absolute land use[$1000km^2$]	15	16	32	-15	-19	-31	0	-4	12

note: negative values indicate that exports are larger than imports, thus the land is used for consumption in other regions

5 Exploring the future

Given the earth's diminishing resources and growing population, it is imperative to prepare for the future if the current level of welfare is to be maintained or expanded. Here we map the current trajectory of the food systems, along with a couple alternative scenarios, in order to examine deeper what the extrapolation of current trends imply in terms of future food availability and environmental impacts (energy use and greenhouse gas emissions). The scenarios developed here are meant to be exploratory rather than predictive.

Our scenario projections involve two components: consumption patterns and environmental impacts. Projections of consumption patterns have been carried out in several studies. Results from FAO[52] (2006b) and IC2 (2007) were used here for the baseline scenarios (S1a and S1b respectively). Both sources use the same historical consumption/production data (from FAOSTAT), however they differ in their projection methods. One important difference is that the IC2 scenario is based on the general equilibrium model GTAP (Global Trade Analysis Project). Here, the *monetary* values projected by GTAP for the future have been directly used to project the future *physical* quantities starting from the base year (2000). This approach has the disadvantage of not considering decoupling of economic and physical growth as a consequence of the stronger growth of high value added products in the last decades. On the other hand, the FAO model is a dynamic partial equilibrium model, which uses single commodity modules with feedbacks to the world market (Alexandratos, 1995). We have also developed an alternative consumption scenario (S2) that represents reduced availability of high-impact foods relative to the baseline scenario S1a. Details about the consumption patterns in 2050 for each scenario can be found in Table 22.

Table 22: Index of consumption changes for scenarios S1a, S1b and S2, in 2050 relative to 2000 (1.00).

	W Europe			USA			China		
Food category	S1a	S1b	S2	S1a	S1b	S2	S1a	S1b	S2
Cereals	0.96	0.88	1.06	0.96	0.83	1.06	0.87	0.97	0.87
of which, rice	0.96	0.90	0.86	0.96	0.85	0.86	0.87	0.98	0.77
Roots	0.85	1.04	0.95	0.85	1.01	0.95	0.81	1.62	0.91
Fruit and veg	1.16	1.16	1.26	1.12	1.12	1.22	1.31	1.31	1.41
sugar and sweeteners	0.97	0.97	0.87	0.97	0.97	0.87	1.72	1.72	1.62
oils	1.12	1.06	1.02	1.12	1.07	1.02	1.60	1.61	1.50
meat	1.14	1.13	0.99	1.14	1.08	0.99	1.83	1.65	1.39
of which, bovine	1.00	1.11	0.70	1.00	1.13	0.70	3.91	1.79	1.41
of which, pork	1.15	1.14	1.02	1.00	1.05	0.90	1.38	1.63	1.33
of which, poultry	1.32	1.14	1.22	1.36	1.05	1.31	2.17	1.63	1.57
milk	1.06	1.09	0.96	1.06	1.06	0.96	2.12	1.75	2.02
other	1.13	1.13	1.13	1.06	1.06	1.06	1.27	1.27	1.27
GDP/cap	3.1	n/a	n/a	3.1	n/a	n/a	12.5	n/a	n/a
Population	1.13	1.02	n/a	1.13	1.38	n/a	1.20	1.09	n/a

note: light gray cells indicate own estimation of sub-category, which corresponds to the category values and follows long term trends (see Appendix 6 for details). For dark gray cells, no category values were available, so long term trends were extended according to the scenario assumptions (see also Appendix 6).

[52] FAO projections did not correspond exactly to the regions analyzed here. Western Europe and the USA fall under 'Industrialized countries' and China falls under 'East Asia' in the FAO projections.

Projections of environmental impacts are based on a time-series analysis of each stage in the food production system. The analysis consisted of identifying, first, the trends in structural activity (e.g., tonne-km/kg of food for the transport stage), and second, the trends in energy intensity within each stage (see Table 23). These trends represent the average of all food commodities. However, we saw from the food product analysis that the impact at a particular stage differed by food product[53]. In order to account for these differences, the structural activity was assessed for each food product category, with the relative differences in impact maintained at 2000 levels[54] (see Appendix 6).

Table 23: Energy projection assumptions for the baseline impact scenarios

Stage	Average annual structural activity change				Average annual energy intensity change (see note 0)			
	W Europe	USA	China	unit	W Europe	USA	China	unit
Agriculture	see note 1			kg $food_{category}$	no clear trend, assumed constant			M J /kg $food_{cat}$
Fertilizers	-1.2%	-1.4%	-0.8%[2]	kg nutrient / kg $food_{cat}$	-0.8%[6]	-1.0%[6]	-1.4%[6]	MJ / kg nutrient
Transport	1.1%	0.4%	1.1%[3]	t-km / kg $food_{cat}$	0.0%[7]	0.0%[7]	4.0%[7]	MJ / t-km
Processing	1.8%	1.7%	4.7%[4]	GDP(PPP) / kg $food_{cat}$	1.2%[8]	0.7%[8]	1.2%[8]	MJ / GDP(PPP)
Packaging	see note 5			kg material	assumed constant			MJ / kg material

notes: 0. A positive energy intensity change indicates that, not counting a shift in production (e.g. increased meat, decreased grains), more energy is was used during a particular stage than the year before. In contrast, a negative value for energy intensity change indicates a gain in energy efficiency, i.e. a lower use of energy for a given output. 1. Agriculture: the availability of each commodity is the most important determinant of environmental impact, thus no additional structural activity indicator was needed. 2. Average change 1990-2000. China has reversed the earlier trend of increasing nutrients used per kg food consumed. 3. China experienced a very large growth rate (7.5%/yr) before 1990, which has slowed significantly to almost no growth between 1990 and 2000. We assume the overall trend will increase over the time period, but at a rate equal to W Europe (the region with the higher growth rate). 4. China's historical data contains jumps which makes the time series implausible, therefore the past GDP/kg food data do not fit as neatly as in Western Europe and the USA. Nonetheless the projected GDP growth rate and projected total food availability growth rates of the respective scenarios were used. 5. Packaging: Overall food packaging use (by weight) shows strong signs of stabilizing in W Europe and the USA, thus it is assumed at 90 and 100 kg/cap respectively for 2050. The values for China are based on projection from Hoornweg (2005). The breakdown of material used in packaging was based on extrapolations of trends in material share (i.e. not on absolute values per material rather than the percentage of all food packaging activity). 6. Incorporates continuation historic efficiency improvements for N, P and K based fertilizers as well as trends in the mix. 7. Levelling out in W Europe and USA; in China the energy intensity is still rising, but it is assumed to level out at USA levels (the higher level of the two). 8. Because of the jumps in historical data, the improvement was estimated to grow at the same rate as W Europe (the higher rate of the two).

Greenhouse gas emissions were projected for the future by multiplying the energy use by emission factors for 2050. For fertilizers and packaging, the emission factors were a continuation of previous trends. For the other stages, they were determined from fuel mix projections, which was based on medium-term baseline projections by the IEA for 2030 with the trend extended to 2050. The assumed emission factors and fuel mix are given in Table 24. For the non-energy sources of emissions from agriculture, emission projections were based on the consumption scenarios, where enteric fermentation emissions changes corresponded to the change in bovine meat and milk availability, manure management corresponded to bovine and

[53] For example, the energy use per kilogramme of pig meat during the fertilizer stage is 3.6 times the average of all food during the fertilizer stage in Western Europe in 2000; during transport it is 1.5 times the average.
[54] This includes the assumption that the structural activity per kilogramme of food for each category is proportional to the energy use of that category. For example, energy use of pig meat during transport was 1.5 times the average food product, thus it is assumed that pig meat also accounts for 1.5 times the average tonne-kilometers.

pig meat and milk availability, soil management to N-fertilizer consumption, and rice cultivation to rice availability (see Appendix 6).

Table 24: Share of fuels and emission factors projected in 2050 (based on IEA, 2007)

	Electricity[1]			Industry[2]			Agriculture[2,3]			Transport[2]		
Fuel share	W Eur.	USA	China	W Eur.	USA	China	W Eur.	USA	China	W Eur.	USA	China
Coal	0.32	0.54	0.81	0.04	0.05	0.48	0.00	0.00	0.33	0	0	0
Heavy Oil	0.03	0.01	0.01	0.25	0.33	0.10	0	0	0	0.14	0.05	0.11
Diesel	0	0	0	0	0	0	0.64	0.62	0.49	0.77	0.91	0.87
Natural Gas	0.33	0.13	0.03	0.31	0.29	0.04	0.18	0.17	0.00	0	0	0
Electricity[4]	-	-	-	0.3	0.2	0.3	0.14	0.13	0.19	0.00	0.00	0.00
Other	0.32	0.32	0.15	0.1	0.13	0.08	0.04	0.08	0	0.09	0.04	0.02
Total	1	1	1	1	1	1	1	1	1	1	1	1
Emission factors [$kgCO_2/MJ_{primary}$]	53	63	84	80	78	122	62	70	89	68	71	73

notes: 1. Primary energy share. 2. Final energy share. 3. Values held constant from 2000. IEA projections did not separate agriculture from residential/commercial energy use. 4. Average efficiency assumed 40%.

The baseline impact scenario, which is used for S1a, S1b and S2, represents a continuation of historic trends, while an alternative scenario, S3, approximates an across-the-board energy efficiency improvement (i.e., a decrease in energy intensity) of 0.25% per year, or 13.3% over 50 years (for all stages listed in Table 23). For the alternative impact scenario, we assume the consumption pattern will be the same as S1a. The two alternative scenarios, one for low-impact consumption patterns, the other for increased energy efficiency, will be compared to the baseline scenarios.

Figure 15 shows the results for each scenario. The overall impact in terms of energy use is on track to increase modestly in Western Europe and the USA, to around 1.3-1.4 times the levels in 2000; GHG emissions are set to roughly stabilize on a per capita basis. China on the other hand is on track to more than double its per capita energy use and GHG emissions, but still at levels significantly lower than Western Europe or the USA. Considering the goals regarding greenhouse gas emissions, these scenarios show that a departure from the current trends is necessary in order to avoid the highest risks from global warming. Of particular interest are the transport and processing stages, which are set to increase substantially.

The historic results from Section 4.2 have shown that relatively modest differences in availability of high-impact foods (e.g. bovine meat) could have a significant effect on the total environmental impact. This is illustrated in Figure 12 (Section 4.2) where USA consumption patterns would use around 1.25 and 1.4 times the energy and emissions as Western European consumption patterns, despite relatively similar availability. However, as the comparison of scenario S2 with the baseline projections shows, the magnitude with which consumption patterns affects the overall energy use/GHG emissions is diminishing. S2 differs little from S1a in energy use, and only 5-10% in GHG emissions. This is the case because of the relative decline of the agriculture stage (where the food categories differ to the largest extent - beef has a relative energy impact of 9.2 times the average in Western Europe) and the relative ascent of transportation and processing stages (where the variation of impact among the food categories is smaller - the maximum relative impact is 3.6 and 3.1 times the average respectively). Modest gains in energy efficiency, represented by scenario S3, have a larger impact on energy use and a comparable impact on GHG emissions as do the consumption pattern changes in scenario S2.

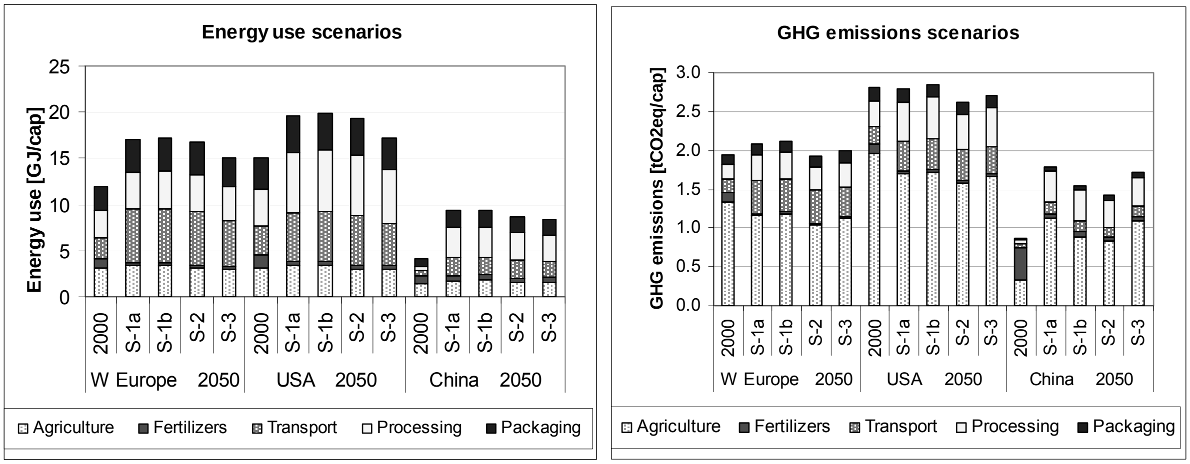

Figure 15: Energy and GHG emission scenarios of the food chain for 2050
note: impacts from indirect emissions, e.g. from N_2O emissions, are included.

If, however, the commodities were categorized differently – for example locally produced versus imported, or minimally processed versus highly processed – the effect of changes in food availability would intensify, rather than diminish with time. It is therefore important to stress that the consumption patterns referred to here indicate the mix of food categories at the primary level (e.g., cereals, fruits and vegetables, milk). Thus, for the current situation, food decisions based on primary-level categories (e.g. vegetarianism) results very large greenhouse gas emission savings. However in the future the cumulative effect of other characteristics will likely play an increasingly important role, especially with regard to transport and processing.

It should also be stressed that these results rely on a continuation of past trends in structural activity and energy efficiency. It is certainly plausible that, for example, transport and processing activity will reach saturation levels. In this case the results would change significantly. For example, if the structural activity for processing and transport were to continue at the same rate until 2025, then stabilize thereafter, per capita energy use in Western Europe would increase by only 19% instead of 43%, while GHG emissions would decrease 4% rather than rise 7% compared to 2000 values. The lesson from this is that the current trends point to large increases at the transport and processing stage, and that if future impacts are to be minimized, there needs to be action taken at these stages.

Finally, we take a look at some scenario projections for land use. The land use projections are based on two factors: the future amount of crops initiated for food/feed consumption and the future land use requirements. The consumption projections, which differ for each scenario (excluding S3), were used to determine the amount of crops initiated for food consumption in the same manner as outline in Section 4.1. The change in the amount of crops initiated for feed consumption was assumed to mirror the changes in meat consumption. The land requirements, shown in Table 25, were assumed to decrease, although at a slower rate than during the recent past. The yearly rate of change was assumed to be 25% of the average yearly change from 1970 – 2000[55] (see Appendix 6) for each commodity group.

[55] This percentage roughly corresponds to the projected improvement in land use productivity for major crops in the IC2 study.

Table 25: Land use requirements [m^2/kg] assumed for scenario projections in 2050

	W Europe		USA		China	
	2000	2050	2000	2050	2000	2050
Cereals	1.7	1.3	1.7	1.3	2.1	1.5
Roots and Tubers	0.3	0.2	0.2	0.2	0.6	0.5
Vegetables	0.4	0.3	0.4	0.3	0.5	0.5
Fruit	0.9	0.8	0.4	0.3	1.4	1.1
Sugar crops	0.2	0.1	0.2	0.2	0.2	0.1
Oilseeds	4.7	4.4	4.6	3.9	6.2	4.8

The land use projections are shown in Figure 16. On a per capita basis, Western Europe and the USA are projected to continue their decline, while China levels out. However, population increases in the USA and China will cause significant increases in absolute land use in these regions, with the USA increasing by around 20% and China around 10%. In China this extra land use would likely occur abroad.

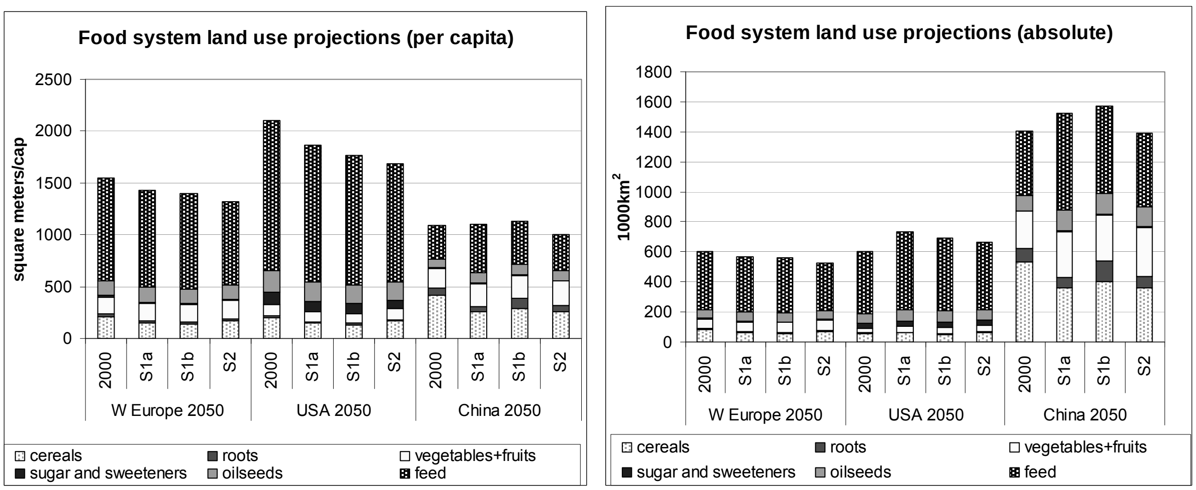

Figure 16: Land use projections for 2050[56]

[56] Note: for the absolute calculations, population increases were assumed to follow those from the IC2 study because they were available for each of our regions rather than aggregates (as in the FAO study).

6 Discussion

An important consideration in this type of research is the quality of the data. Data quality issues have been alluded to earlier; here we examine explicitly some of them and the consequences for the robustness of the results. First, regarding consumption patterns, the availability reported by FAO food balance sheets is a derived statistic, meaning it is not directly measured but calculated based on other measured and estimated quantities. As such, the quality of availability data is dependant upon the other data used to derive it. The uncertainty is particularly high in developing countries, as we have seen with fruit and vegetable consumption in China. On the other hand, household budget surveys do attempt to measure availability directly, but are limited in that they extrapolate results from a relatively small sample to the country as a whole. In Western Europe there was an additional problem in that each individual country used different classification systems, which was then harmonized afterwards. (For a discussion about the differences in FBS and HBS, see Appendix 1). Together, these consumption data quality issues, although unavoidable, add uncertainty and weaken somewhat the results.

In the food product analysis, a major data issue was the limited coverage. Table 26 shows the portion of each food category that was covered by a product-specific energy and GHG emission factors. However, this understates the problem, as many of the product-specific factors were actually averages for a mix of products within that category. For example the estimated energy and emission factors for fresh fruits were averages of apples, oranges and bananas, assumed to represent the entire fresh fruit category. For fruits, the portion that is excluded from Table 25 is dried and canned fruit of all types (more details can be found in Appendix 4). Another critical factor for the food product analysis was the outstandingly high values for beef. These values were determined from two sources (Nielsen et al., 2003 and Williams et al., 2006), but additional verification would have been preferred. As a result, the food product analysis alone is not detailed enough for strong conclusions to be derived from it. However it is hoped that by combining it with the system level analysis, the robustness is strengthened.

Table 26: Category coverage of food product analysis.

	Western Europe			USA			China		
	1970	1990	2000	1970	1990	2000	1970	1990	2000
Cereals	85%	82%	79%	69%	66%	69%	72%	84%	89%
Roots	75%	75%	75%	94%	94%	93%	100%	100%	100%
Vegetables	100%	100%	100%	89%	90%	100%	100%	100%	100%
Fruit	95%	97%	98%	83%	87%	88%	100%	100%	100%
Sugar	97%	93%	91%	85%	49%	45%	89%	93%	91%
Oil	100%	100%	100%	100%	100%	100%	100%	100%	100%
Meat	91%	93%	92%	98%	99%	99%	100%	100%	100%
Milk	90%	91%	90%	80%	87%	90%	100%	100%	100%
Other categories[1]	21%	20%	19%	17%	16%	15%	5%	9%	12%

note: 1. The value for 'other categories' is the percentage of total availability, whereas the value in each food category is the percentage of that category which is covered.

This is not to suggest that the system level analysis was without serious data issues of its own. For example some data from the IEA contained jumps or missing values. Furthermore many of the time series values for China had to be estimated because data was simply not available (e.g., in packaging and during scenario construction). In general it can be said that a rigorous methodology was sacrificed the hopes of producing more realistic estimates, and if fact in many cases it was necessary to produce any estimate at all. In the absence of uniform, reliable data (a problem likely to persist for some time), such trade-offs are inevitable for the practical purposes of estimating environmental impacts of entire regions. However, the strength with which we put forth our conclusions is diminished by the large uncertainties, especially for the Chinese situation.

One further data issue should be brought to attention. Because agricultural GHG emissions are such a dominant source compared to the other stages, the associated uncertainty is particularly important. Above all N_2O emissions for a particular crop or animal can vary widely depending on a host of conditions, including climate zone and soil conditions. In the food product analysis, emission factors for each type of crop or animal was implicitly used. Because these factors could not adequately account for all the variable climatic/soil conditions, the resulting uncertainty is very large. However, for the system level analysis, uncertainty ranges have been quantified as part of the GHG inventories, for the USA it is shown in Table 27. These ranges, although quite large, will not change the conclusion that GHG emissions at the agriculture stage are by far the most important. However the uncertainty should not be overlooked in comparing changes over time and between regions.

Table 27: Uncertainty range of agricultural GHG emissions in USA GHG inventory (Source: EPA, 2007)

enteric fermentation:	11% to +18%
manure management:	18% to +20% CH_4
	16% to +24% N_2O
rice cultivation:	70% to +170%
soil emissions:	20% to +22% direct N_2O
	42% to +135% indirect N_2O

In addition to data issues, the choice of the scope and functional unit impact the quality of the results. The functional unit that was used in this study – kilogramme of food product – may be criticized on the grounds that it does not adequately reflect the role that food fulfils. Other units such as calorie or protein content have been suggested as alternatives. However each suffers from shortfalls, for example alcohol is not typically consumed for its calorie or protein content. Table 28 shows the average values for food categories, based on the breakdown of food products in Western Europe in 2000. If the calculations were based on a caloric functional unit, those categories with a higher than average kcal/kg ratio would have a reduced impact than calculated in this report.

Table 28: Ratio of calorie content to mass in Western Europe 2000.
Source data: FAOSTAT 2007

	kcal/kg
Cereals	2768
Starchy roots	652
Vegetables	248
Fruits	423
Sugar/sweetener	3519
Oil	8924
Meat	1736
Milk	482
Other	1235
Average	1246

It should also be acknowledged that this study has not taken into account the full extent of environmental impacts. Other impacts such as eutrophication, acidification and desiccation, to name a few, may lead to different assessment of the impact of a stage or product.

Finally, we must point out some of the assumptions upon which the results depend. In the scenarios for the future, we found that consumption pattern differences are likely to play a diminishing role in energy and GHG emissions. This follows from two findings: (1) the difference in impact of the food categories is larger at the agriculture and fertilizer stages than at the transport and processing stages, and (2) transport and processing has been increasing faster relative to the previous stages. However, the results of the scenarios also hinge on a key assumption: that the structural activity at each stage (e.g., tonne-km for transport) grows at the same rate for all commodity groups, thus maintaining the relative difference in impact.

7 Summary and conclusions

In this research we were able to assess the environmental impact of the food system in terms of energy use, greenhouse gas emissions and land use, comparing Western Europe, the USA and China. Regarding the methodology, two largely independent methods, the product level analysis and the system level analysis, were successfully developed and applied. The fit between the two was good for agriculture and fertilizers, but not for transport and processing. The data required to conduct the system level analysis were usually available and of good quality for Western Europe and the USA while some serious data gaps and inconsistencies were encountered for China. For the product analysis, data availability fell short of the desired level, however it was enough for a preliminary investigation. Nevertheless the empirical results derived (the levels and trends found for key indicators) are expected to be valid (see below).

The main empirical conclusions are as follows:

- Within industrialized regions, the USA has used significantly more energy on a per capita basis and emitted more GHG (+50%/cap) than Western Europe. China, on the other hand, has a much lower environmental impact, at around a third of the level of Western Europe.
- The energy use and GHG emissions for the entire food system (from cradle to factory gate), were estimated at 12.0 MJ/cap and 1.97 $tCO_{2\text{-}eq}$/cap in Western Europe (the average of the product analysis and system level analysis at each stage); 15.1 MJ/cap and 2.83 $tCO_{2\text{-}eq}$/cap in the USA; and 4.1 MJ/cap and 0.88 $tCO_{2\text{-}eq}$/cap in China for 2000. In the developed regions, per capita energy use has increased on average around 1% per year since 1970, whereas in China it has increased more than twice as rapidly. Per capita greenhouse gas emissions from the food system have declined slightly from 1970 levels in the USA and have remained unchanged in Western Europe, however they have increased at an average rate of 1.6% per year in China.
- The differences in energy and GHG can be explained to a large extent by the types of food consumed, thus reducing consumption of high impact foods, e.g. bovine meat, can have a substantial impact. Other recent developments such as convenience food do not seem to have a strong impact on the overall environmental impact, with the impact confined primarily to processing. However, the increase in food transport might be partly related to the continuously rising degree of processing
- In industrialized countries, despite increasing energy use in the food system (around 50% since 1970), per capita emissions have not been increasing. This is mainly due to stabilization in emissions at the agriculture stage, which is by far the most important stage for emissions. As such, increased attention could be devoted to this stage in order to bring about a reduction in GHG emissions over the entire food system.
- Yield increases have resulted in declines or stabilization in land use in industrialized countries, however in China rising meat consumption has triggered expanding land use. A significant share of the increasing land used for oil seed production is taking place abroad.
- A look at possible futures reveals that transport and processing are quickly increasing their contribution to the overall environmental impact of the food system. Comparing these stages to the agricultural stage, the food categories differ less in their relative impact. As processing and transport become more important, shifts in the consumption of food categories will have less of an effect on the environmental impact. Efforts aimed at improving energy efficiency, thereby affecting all categories, can go a long way towards reducing the impact during transport and processing.

- In conclusion, if the currently predominating trends proceed, it will not be possible to stabilize – let alone reduce – energy use and GHG emissions from the food system. Given the overall contribution of energy and GHG emissions of the food system in the entire economy, these are distressing results. Concerted action between industry and R&D should be taken to identify, develop and implement saving measures for energy and GHG emissions.
- Additional research is needed in order to support many of these findings (because of some data quality issues), and to look into other aspects of the food system not studied here, especially the use stage of the life cycle, which is likely to account for a very large share of the total impact in the food system. Another aspect which could be explored more thoroughly is food loss. The current rough estimates indicate that reduction this waste holds substantial possibilities for decreasing the environmental impact of the food system.

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Appendices

Appendix 1: Detailed consumption information

1A. Food balance sheet detailed results

Figure A1.1 shows year by year availability of some major commodities. The world average and developed/developing countries are included.

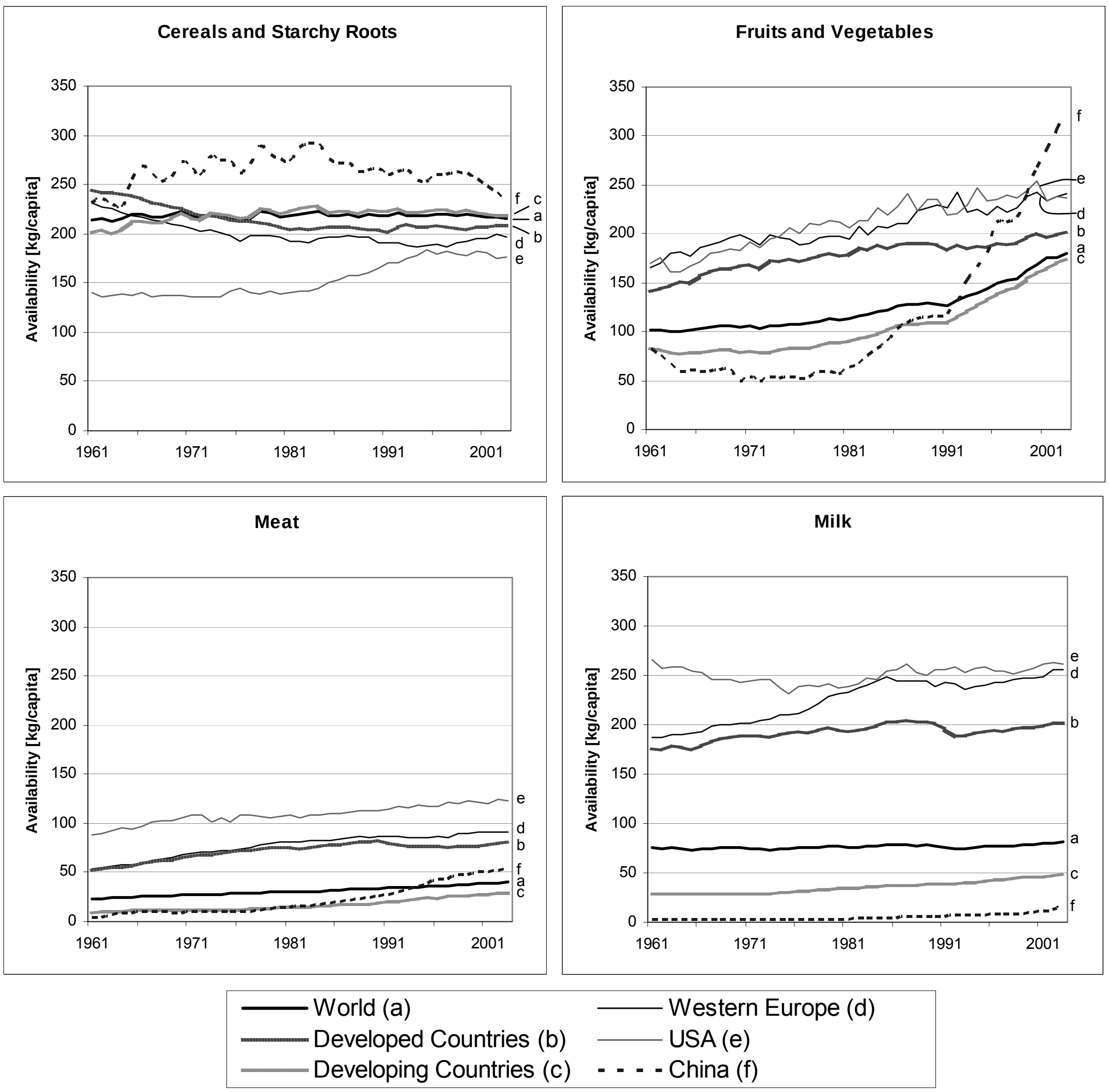


Figure A1.1: Food availability in selected regions and countries. Source data: FAO, 2007

1B. Household budget survey detailed results

In order to identify trends in processed commodities we must look to other data sources beyond the FAO food balance sheets. Household budget surveys and market statistics report food products in the form in which it is purchased by households, allowing us to assess changes in processing technology, preservation method and level of convenience. Household budget surveys are carried out by national governments, sometimes at irregular intervals and with varying methods and classification schemes, making the data difficult to compare. To overcome this, the DAFNE has post-harmonised data for several countries in Europe and time periods (Dafnesoft, 2007). DAFNE data, along with the Household Food Survey in the UK (DEFRA, 2007) will be examined here. The DEFRA data is useful because it is available for longer time period, and recent editions also collect information on out-of-home consumption, in contrast to the DAFNE data which only includes in-home consumption. This data will be further supplemented by market statistics, which essentially report the same: availability at the household level (source: GMID, 2007). This data is comprehensive across countries but is only available for a short time span reaching back to 1997.

The data from DAFNE is shown in Table A1.1 for four countries in Western Europe for which an adequate time span is available. Table A1.2 shows (non-harmonized) meat availability in the UK. Figure A1.2 shows another aspect of final products in Western Europe, namely the preservation method.

Table A1.1: Household availability in selected European countries. Source Data: DAFNE, 2007

	Availability [kg/capita/year]										
	FRANCE		GREECE			SPAIN			UK		
	1985	**1991**	**1981**	**1987**	**1998**	**1981**	**1991**	**1999**	**1985**	**1990**	**1999**
Fruit	59	57	n/a	128	119	106	112	83	39	45	53
Fresh	57	56	121	124	111	102	104	69	27	31	36
Processed, not juice	1.6	1.6	n/a	3.6	0.2	1.4	1.1	1.7	4.4	3.7	2.8
Fruit Juices	n/a	n/a	n/a	n/a	8	2.8	6.6	10.6	7.7	10.2	14.6
Vegetables	66	67	n/a	96	100	76	65	44	58	57	55
Fresh	59	57	n/a	92	92	69	57	38	38	37	38
Processed	7.3	9.5	4.7	4.4	8.4	7.3	8.8	6.6	20	19	18
Frozen	2.7	5	1	1.2	2.2	0.7	1.6	1.8	5.2	5.7	4.4
Canned	n/a	n/a	2	1.5	4.2	3.2	3.8	4.7	14	12	11
Meat	62	59	55	64	54	68	64	51	54	50	47
Fresh	45	41	52	52	51	51	47	34	30	28	24
Red	32	28	41	40	37	29	26	20	20	16	12
Poultry	13	13	11	12	14	22	21	14	10	12	12
Meat Products	12	12	2.6	4	3.2	14	15	13	12	10	9.1
Meat Dishes	3.7	5.5	n/a	4.7	n/a	1.4	1.4	2.6	11	11	14
Cereal Products	171	160	291	206	170	292	323	253	212	200	202
Bread	125	115	213	162	135	177	218	167	125	111	103
Bakery products	4.4	4.4	34	10	12	9	21	18	38	40	44
Rice/cereal prod.	17	17	24	17	13	18	26	18	26	29	36
Flour	9.3	8	9.8	6.9	0	64	30	22	16	12	7.5
Pasta	15	16	10	10	10	24	28	28	7	7.7	11
Dairy Products	270	290	424	398	341	273	318	299	364	331	320
Cheese	46	48	13	19	15	41	55	53	22	22	20
Milk	182	181	391	342	279	205	226	219	318	279	260
Milk products	42	61	20	37	47	27	37	27	24	30	40
Sugars	30	22	37	25	16	44	39	26	34	24	15
Vegetable oil	24	21	79	63	47	78	82	86	4.2	6.1	6.7

note: Subcategory values may not sum to category values on account of rounding errors.

This data was used to estimate the share of processed food type in each category for Western Europe (see Section 2.2, Table 1). To calculate averages for 2000, the most recent year was used, and for 1990 the year nearest that year for all countries. When only one value was available in a country then that value was excluded (e.g., Greece fruit juices).

Table A1.2: UK Availability of meat. Source data: DEFRA, 2007

	Availability [kg/capita]					
	1974	**1984**	**1994**	**2003-2004**	**Overall average annual change [%]**	**Ave annual change 1994-2003-4[%]**
Total meat and meat products	53.3	55.8	51.2	55.3	0.1	0.9
carcase	20.5	21.5	20.6	11.7	-1.9	-6.1
non-carcase	32.9	33.5	34.2	43.6	1.0	2.7
Uncooked poultry and ham	12.6	14.5	13.8	14.1	0.4	0.2
Cooked poultry and ham	1.6	2.0	2.9	5.0	4.0	6.2
Ready meals and convenience meat products	1.4	-	5.4	8.1	6.2	4.6
Other meat products	17.2	17.1	16.2	16.5	-0.1	0.2

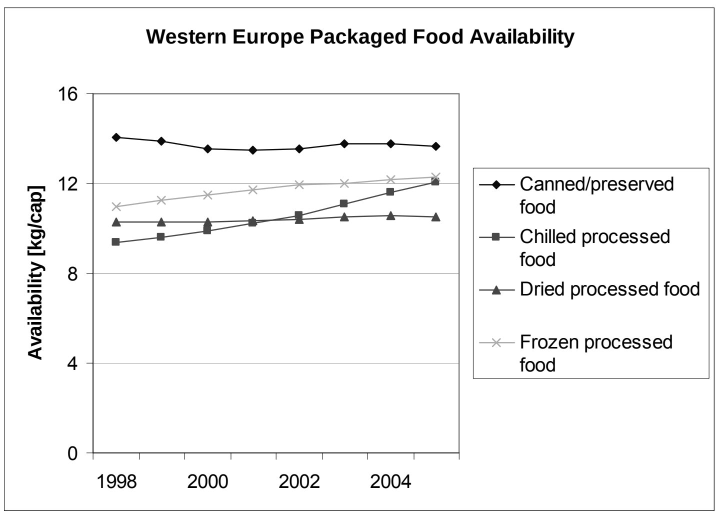


Figure A1.2: Western European food availability by preservation method. Retail packaged food excluding dairy. Source data: GMID, 2006

Note: A large portion of packaged food - bread and bakery products - is not shown in the figure.

The following additional observations, not mentioned in Section 2, can be made from the above tables and figures:

- There are very large differences between countries within Europe, especially for fruit. This can be attributed to varying local conditions with respect to climate, crop cultivation, culture, etc. However these differences seem to be shrinking; convergence is especially visible for fruits in Table A1.1. Greece and Spain, where fruit availability is high, have experienced declining availability meanwhile the UK, with low levels, has increased its fruit availability. The trend towards convergence of fruits (and to a lesser extent vegetables) was also identified by Naska et al. (2006) is their study of 10 European countries included in DAFNE. Meat availability as a whole is quite similar across countries, however there remain rather large differences in the subcategories.

- For fruits and vegetables in Western Europe, in countries where the share of processed food in a category is relatively low, there has generally been growth, whereas if the share is high then there has been a decline. The processed vegetable category illustrates this point. France, Greece and Spain, with 10-15% share of processed vegetables to total vegetables in the 1980s, all experienced growth during the next decade. On the other hand, the UK, with a processed vegetable share above 30% of all vegetables, experienced a decline. Also, there appears to be indications of convergence between the countries with respect to the share of frozen and canned foods.
- From Figure A1.2 we see that frozen and chilled foods are increasing, while canned and dried food availability is not.

<u>1C. Differences in FBS, HBS and Intake surveys</u>

There are significant differences between availability as reported by FAO food balance sheets and household budget surveys. It varies depending on category, but a comparison of availability shows significantly lower availability according to HBS (up to 40%). In part this is because HBS neglect out-of-home consumption (with the exception of the UK after 2000). The methodological differences are also important. In food balances the accuracy of availability, which is a derived quantity, is dependant on the accuracy of other reported statistics, such as production, trade and waste. While these errors cannot be neglected, for most developed countries, the statistics are generally considered to be of good quality (FAO, 2007).

Individual Dietary Surveys (IDS) are carried out by many national governments measuring the intake of certain segments of the population. This type of survey has the advantage of recording the amount of food consumed, in contrast to availability as recorded by HBS or food balances. However, data on the basis of food product are generally not comparable with either HBS or food balances on account of differing classification systems. Instead, they can be compared by converting the food products into energy, as Figure A1.3 shows for the USA and UK.

The difference between availability and intake is the food waste after the household gate. Therefore comparing the two consumption results should in principle shed light on household food waste.

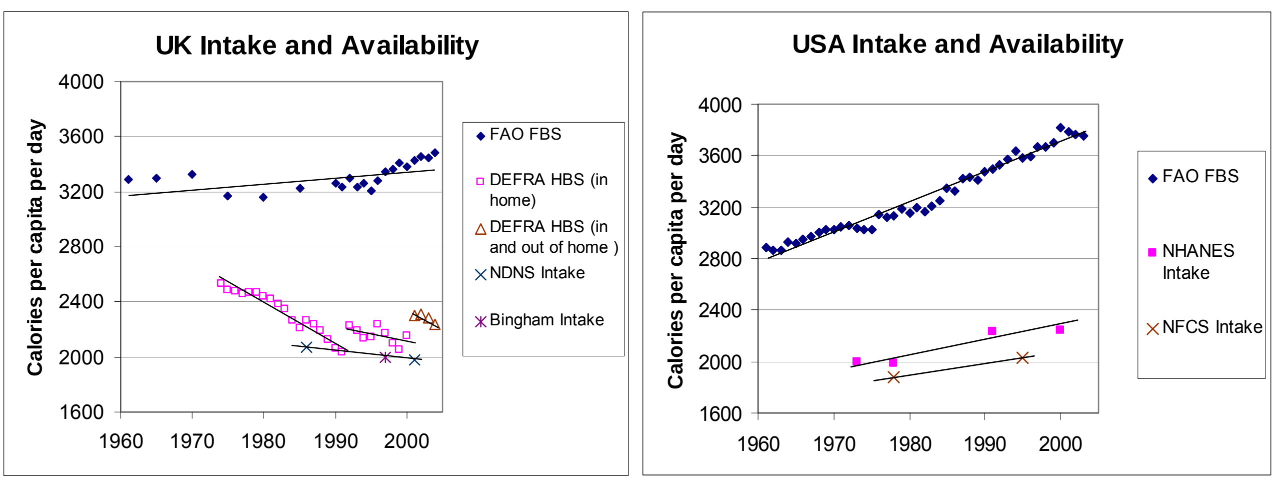


Figure A1.3: Comparison of intake and availability data in the UK and USA
Note: From 1992 on softdrinks were included in DEFRA HBS datasets.

For the UK, a comparison of the HBS availability data and the NDNS intake data, which are rather similar in their collection methods[57], appears to show signs of convergence, indicating a reduction in household waste. However, uncertainty is too large to state this with confidence because of the following:

- NDNS data is for adults 19-64 only, representing 59.3 and 60.3% of the UK population in 1987 and 2001 respectively. Bingham data is for 45-64 year olds, 23.8% of the population.
- There are very few data points for the IDS.
- HBS data points show rather large scatter.
- There is a high error inherent in the survey methodologies.

Comparing the FAO food balance data to the HBS data, both of which measure availability, we see that there is large and growing gap for the UK, even when out of home availability is included in the HBS data. By 2004 the HBS energy intake was just 64% of the FBS value. This result is unexpected, although some difference would be expected on account of the different methods used. Under-reporting is problem frequently encountered in food surveys (both IDS and HBS), and may account for some of the difference. In particular, the share of out-of-home energy intake seems suspiciously low compared to the USA.

The situation is different in the United States, where availability according to the FAO FBS has been growing strongly throughout the time period. Intake data follow this trend. NFCS data represents all Americans over the age of 2, whereas NHANES surveyed only those aged 20-74. They also differed slightly in their methods.

Only since the mid 1990s has the UK FBS availability increased at a similar rate as in the USA. It remains to be seen whether coming intake surveys will measure a similar increase. Both US and UK intake surveys report around 55-60% of the caloric value reported in FAO FBS.

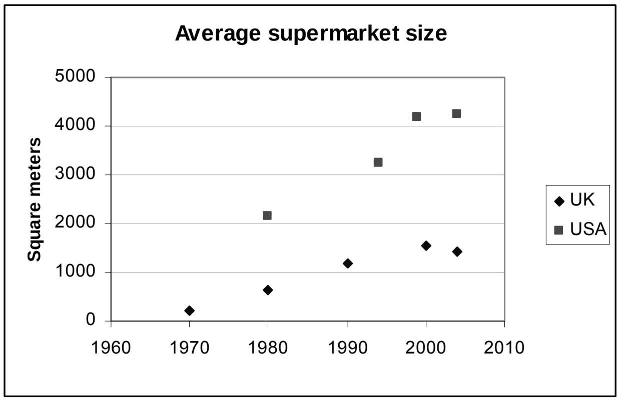
1D. Diversity

The number of products available in supermarkets has increased substantially, as shown in Table A1.3 for the USA. In the 1960s an average European grocery had 2000 product lines, compared to more than 15000 today (INCEPEN, 2003 from EEA, 2004). Furthermore, the average size of supermarkets has increased significantly, and closely related, the number of hypermarkets (greater than 2500 m^2) (See Figure A1.4).

Table A1.3: Median number of products carried by US supermarkets.
Source: FMI, 2007; Kaufman, 2002; Gallo, 1997

	Products
1980:	14,000
1990:	26,000
2000:	40,000
2005:	45,000

[57] Similar in that they both use surveys of the non-military, non-institutionalized population. However important differences are still present. IDS used 24 hour recall, while HRS used food diaries in their surveys.



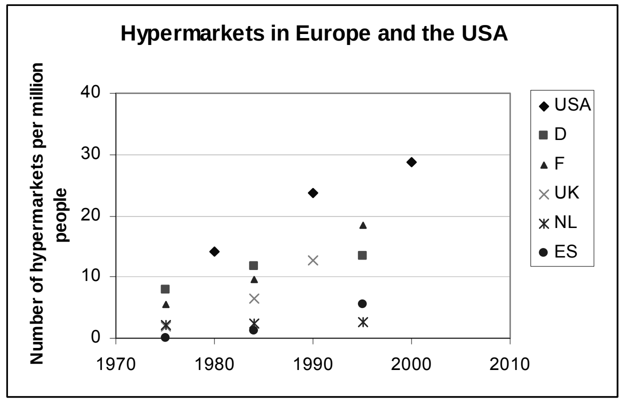


Figure A1.4: Average size of supermarkets and number of hypermarkets in USA and Western European countries. Source: Pilat, 1997

The growing size of supermarkets has increased consumer access to a variety of products, implying greater diversity.

At the household level, a number of studies have examined the degree of diversity as its determinants:

Shonkwiler et al. (1987 from Thiele and Weiss, 2003) found in the US that the number of food products significantly increases with rising food expenditure (and food expenditure increases with rising income);

Jekanowski and Binkley (2000) found in the US that diversity increases with:

- decreasing share of low-income households
- increasing store size
- increasing ethnic diversity

Moon et al. (2002) found in Bulgaria that diversity is lower in the following groups:

- low income
- elderly
- less educated

Theil and Weiss (2003) found in Germany that food diversity:

- increases with growing income
- increases with larger household size (specifically number of children)
- decreases for elderly

Appendix 2: Food loss

Food loss must be defined carefully, as it could possibly encompass all potential produced food which does not end up being consumed by humans, including for example starch for the paper industry or grains for feed. However, here we limit food loss to that which is not used further by the food sector or other industries, but instead is transferred to the waste treatment sector. This can include losses that may be recoverable for human consumption, such as fruit rejected for cosmetic reasons, as well as losses that are not recoverable for consumption, such as diseased meat (Kantor et al., 1997). We look at each stage for losses in more detail.

2A. Agriculture stage

Loss before and during harvest are not explicitly examined, rather they are incorporated in yield data. However, the importance of losses at this stage should not be minimized, as especially severe weather conditions, pests and disease can cause significant losses. Furthermore handling at this stage can contribute to waste in later stages (e.g. mechanical damage to crops, providing pathways for micro-organism growth (FAO and UNEP, 1981)).

2B. Processing, storage and transport stage

Food balance sheets from the FAO contain estimates for waste that occurs in storage, transportation and processing. However there are a couple of major problems with the quality of the data: transport and storage losses are often based on estimates by experts in the country, rather than actually measured; and processing waste is estimated through extraction rates, which can include quantities that are used elsewhere (e.g. as feed), thus overestimating food loss as defined above (Ramirez, 2005).

Fruits and vegetables are most susceptible to transport and storage losses. According to estimates used in FAOSTAT food balances, these losses generally amount to around 5-10% of the supply for the regions studied here. Estimates for the USA are at the lower end of this range, whereas China and Western Europe are at the higher end.

Food loss arising from cereals is generally only significant in developing countries. In China it amounts to around 5% of supply, or around 13 kg/capita, whereas in Western Europe it is 1% of supply or less.

A fairly significant amount of starchy roots are lost across all regions, in the vicinity of 5% of supply. For meat and dairy, estimates are generally low or not available. Sugar and sugar crops are low; oil crops are about 1-3%. Table A2.1 shows losses for the regions calculated from FAOSTAT data.

Table A2.1: Processing, transport and storage losses, average 2000-2003. Source: FAOSTAT

	Supply [kg/capita]	Food availability [kg/capita]	Processing, transport and storage loss [kg/capita]
Fruits and Vegetables			
China	337	295	27
USA	266	241	13
Western Europe	330	239	26

Cereals			
China	264	170	13
USA	882	114	2
Western Europe	500	119	9
Starchy Roots			
China	150	75	7
USA	79	65	6
Western Europe	142	78	8
Oil crops			
China	53	17[1]	2
USA	200	33[1]	6
Western Europe	122	24[1]	2
Sugars and sweeteners			
China	8	7	0
USA	74	71	0.2
Western Europe	52	41	0

note:1. includes vegetable oils

Examining detailed commodity losses provides no clear insight into changes with time (see Table A2.2).

Table A2.2: Detailed look at transport and storage losses for major commodities, as percentage of supply (production + imports + stock changes). Source: FAOSTAT

	China					Western Europe					USA				
	1960s	1970s	1980s	1990s	2000s	1960s	1970s	1980s	1990s	2000s	1960s	1970s	1980s	1990s	2000s
Wheat	4.9	4.9	5.0	5.7	5.0	1.0	1.2	1.3	1.2	1.2	0	0	0	0	0
Rice	4.7	5.3	5.0	4.0	2.2	0.4	0.3	0.2	0.2	0.2	1.3	2.9	6.0	7.9	8.7
Barley	4.7	4.7	4.7	4.8	4.8	1.7	1.8	1.9	1.4	1.3	0	0	0	0	0
Maize	4.9	4.5	4.4	4.5	4.7	0.7	0.8	1.0	1.1	1.2	0	0	0	0	0
Rye	5.6	5.0	5.6	8.7	7.5	2.9	2.8	2.8	2.7	2.5	0	0	0	0	0
Oats	4.7	4.8	4.8	4.5	4.2	2.0	2.1	2.3	1.8	1.8	0	0	0	0	0
Millet	4.5	4.6	4.6	4.3	4.1	0.7	0.2	0.1	0.1	0.3	5.0	5.0	5.0	5.0	5.0
Potato	5.0	5.0	5.0	4.9	4.9	7.3	5.4	4.3	4.9	4.9	6.3	7.9	8.0	7.1	6.7
Soybeans	2.8	2.7	2.0	2.3	1.8	0.9	0.1	0.4	1.0	0.9	4.6	3.5	3.1	4.7	2.1
Tomato	7.5	7.6	8.1	8.1	8.1	10.4	9.4	8.0	6.0	5.5	4.9	4.9	4.8	4.9	5.0
Onion	7.0	7.1	7.2	7.1	7.0	8.9	8.5	8.5	9.0	8.1	5.0	5.0	5.0	5.0	5.0
Other Fruit	10.0	10.0	10.0	10.0	10.0	11.8	11.4	11.5	10.6	9.9	5.7	5.6	5.5	5.5	5.4
Oranges	5.6	6.5	4.3	2.8	1.8	7.0	6.9	8.6	4.7	3.9	2.1	2.1	1.5	1.7	1.9
Bananas	6.2	6.5	8.4	9.7	9.8	7.9	6.8	6.1	5.3	4.5	5.0	5.0	5.0	5.0	5.0
Apples	10.0	10.0	9.9	9.9	9.9	9.7	7.7	6.4	5.5	4.8	5.0	5.0	3.8	3.4	2.9
Milk	4.2	4.3	4.4	4.1	3.8	0.5	0.5	0.6	0.5	0.3	0	0	0	0	0
Butter	0	0	0	0	0	0	0	0	0	0	0.5	0.4	3.5	3.5	1.0

Processing losses in USA and Western Europe have not decreased (or at least this does not show up in the data), despite processing technology improvements and efforts to minimize waste generation. The main reasons have been higher quality and safety standards, which, all else equal, cause an increase in waste (Ctech, 2004).

2C. Retail and consumption stage

Estimates of losses at the retail and household stage are shown in Table A2.3 for the USA. Food availability is based on data from the ERS (2007a), with the commodities recorded are at the semi-processed or final food product level, in contrast to FAOSTAT data, which are recorded at the primary or near-primary level. The data here also exclude non-edible food parts (e.g. bones, pits), also in contrast to FAOSTAT data.

Table A2.3: Food loss estimates at retail, foodservice and household stages, USA 1995. Source: Kantor, et al., 1997

	Food availability [kg/cap]	Retail loss [kg/cap]	[%]	Foodservice and household loss [kg/cap]	[%]
Cereal grains	77	1.5	2	23	30
Fruits, vegetables and potatoes	187	2.9	2	43	23
Meat	86	0.9	1	13	15
Dairy	128	2.6	2	38	30
Sugar and sweeteners	65	0.7	1	19	30
Oils and fats	34	0.3	1	11	32

Appendix 3: Supply structure details

3A. Trade

In this section additional information is provided about trade. Unless otherwise stated, the data is from UN Comtrade (2007). Figure A3.1 shows how much of the food consumption originates abroad (and whether or not the imports are processed). Figure A3.2 and A3.3 show absolute levels of imports, as opposed to the per capita imports in Section 3.1. Finally figure A3.4 illustrates the slow growth of agricultural imports in China relative to the explosive growth in other sectors.

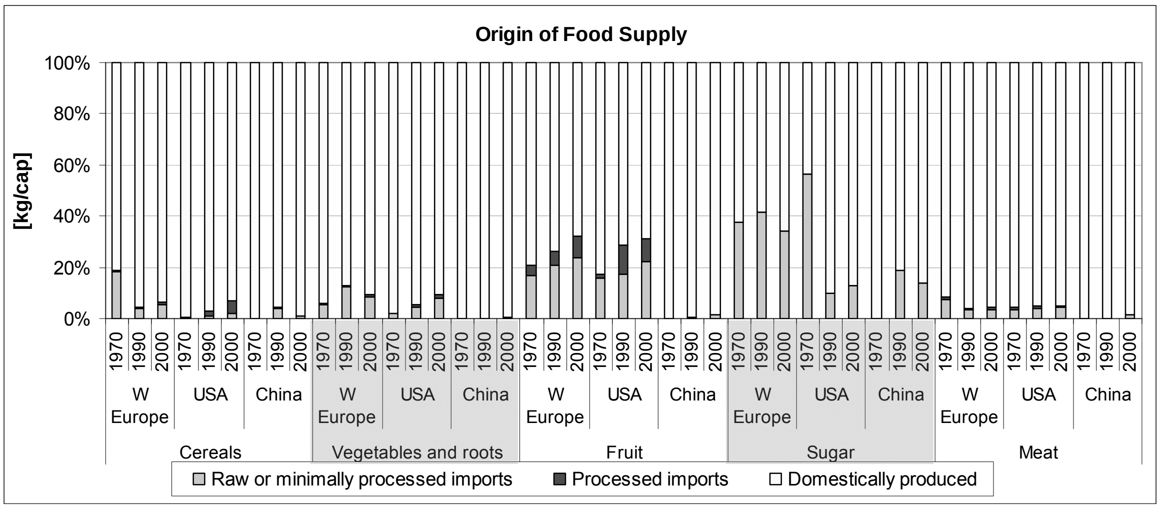


Figure A3.1: Share of food consumption that is produced domestically and abroad. Source: UN Comtrade (2007)

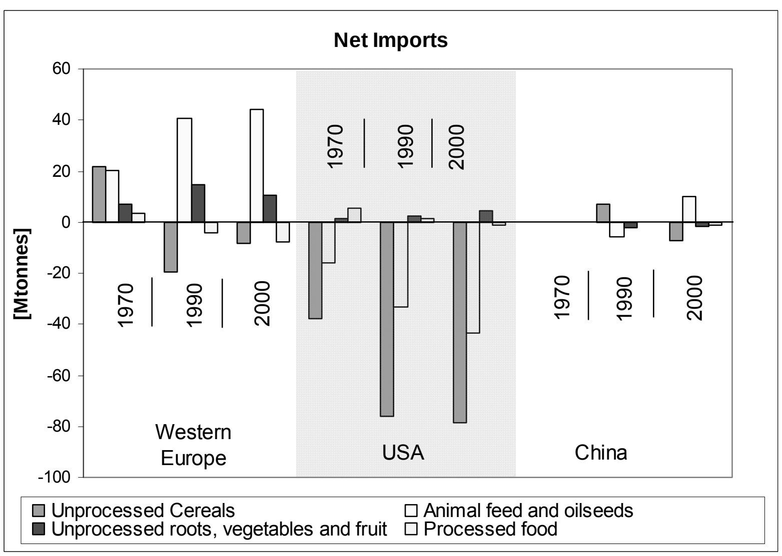


Figure A3.2: Absolute net imports. Source: UN Comtrade (2007)

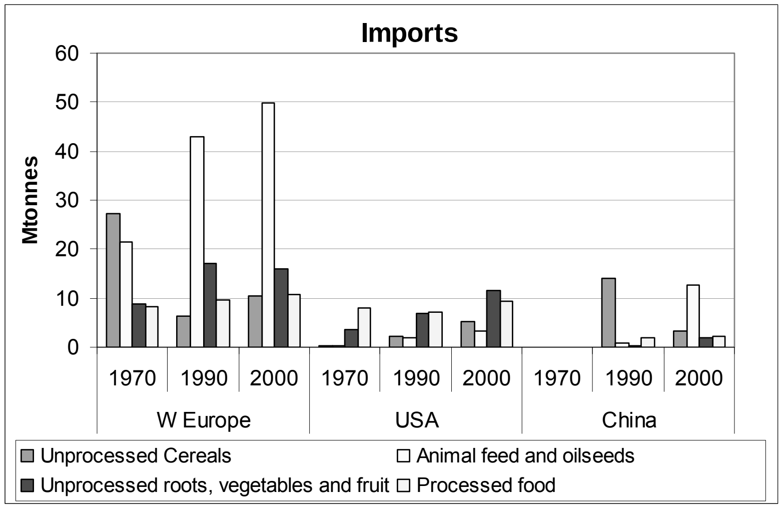


Figure A3.3: Absolute imports. Source: UN Comtrade (2007)

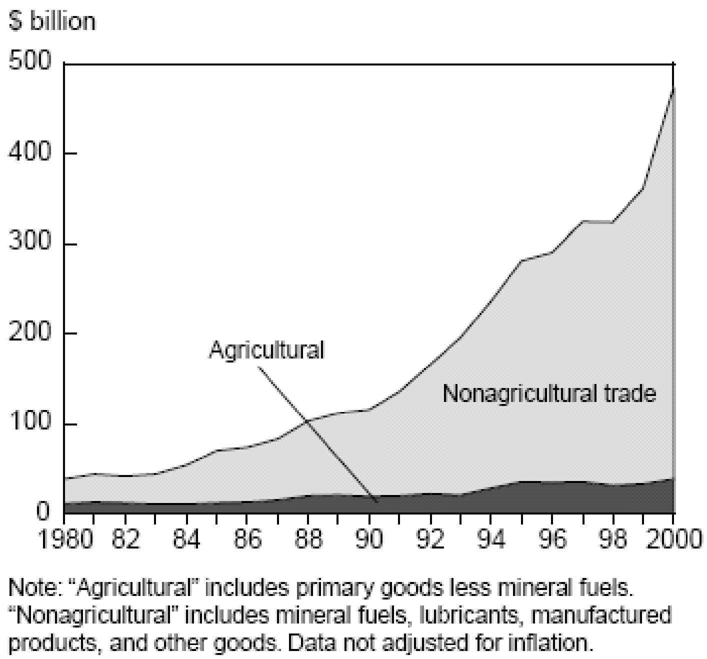


Figure A3.4: China agricultural and nonagricultural trade. Source: Gale 2002

Europe and China are the largest importers of soy. China now imports more than half of its domestic supply of soybeans (FAOSTAT, 2007), accounting for 40% of world soy trade (Ash et al., 2006). This has changed rapidly over couple decades: In 1990 only 9% of China's domestic supply of soybeans was imported. Europe is the other major importer of soy, nearly 100% of its supply, and in absolute physical terms now only just surpassed by China. To meet this demand, production of soy has increased 50 to 60 percent between 1985 and 2000. Most soy is grown in US, Brazil and Argentina. The latter two export 60% and the US exports 16% of their production.

Table A3.1 shows the trade correction factors broken down by commodity group used for transport.

Table A3.1: Detailed trade correction factors for transport

		1970	1990	2000
W Europe	Unprocessed cereals	1.04	0.98	0.99
	Roots, vegetables and fruits	1.07	1.07	1.04
	Oilseeds	1.06	1.06	1.05
	Meat, animal feed and food products	1.01	1.02	1.01
	Live animals and sugar	1.09	1.01	0.98
USA	Unprocessed cereals	0.90	0.85	0.87
	Potatoes and vegetables	0.99	0.99	1.01
	Fruit	1.22	1.16	1.16
	Oilseeds	0.90	0.91	0.86
	Live animals	1.00	1.00	1.00
	Meat	1.01	1.00	0.98
	Animal feed	0.89	0.82	0.84
	Other prepared foodstuffs	1.01	1.00	1.00
China	Cereals and oilseeds	1.00	1.06	1.01
	Other food and feed	1.00	1.00	1.00

3B. Fertilizers

Table A3.2 shows detailed fertilizer consumption in the three regions. These were multiplied by the energy and emission factors from Section 4.3.1.1 and the trade correction factors from Section 3.3 to determine the energy use and GHG emissions.

Table A3.2: Detailed fertilizer consumption [kg/cap]. Source: IFA, 2007 (not adjusted for trade)

	W Europe			USA			China		
	1970[1]	1990	2000	1970[1]	1990	2000	1970[1]	1990	2000
N only									
Ammonium Sulphate	1.72	0.78	0.59	0.75	0.51	0.62	0.29	0.12	0.09
Urea	1.28	3.63	3.78	1.82	4.64	6.12	1.40	7.47	10.19
Amm. Nitrate	4.45	5.63	4.91	4.12	1.84	1.41	0.48	0.60	0.17
Calcium Amm. Nit.	7.35	7.51	5.63	0.03	0.00	0.00	0.00	0.00	0.00
Ammonia direct	0.51	0.33	0.15	13.30	12.37	8.11	0.00	0.00	0.00
Nitrogen solutions	0.71	2.30	2.72	4.60	6.95	7.34	0.00	0.00	0.00
Other straight N	1.00	0.49	0.95	0.94	0.44	0.85	2.87	7.73	4.90
P only									
Single Super Phosphate	2.02	0.59	0.23	0.15	0.01	0.01	1.34	2.45	2.96
Triple Super Phosphate	0.89	1.02	0.70	2.09	0.67	0.41	0.00	0.05	0.05
Slag	2.49	0.33	0.01	0.04	0.00	0.00	0.00	0.00	0.00
K only									
Potassium chloride	2.73	3.49	2.47	7.62	9.15	8.55	0.10	1.12	2.32
Potassium sulphate	0.49	0.36	0.31	0.07	0.24	0.24	0.00	0.26	0.09
Other K	2.25	0.62	0.14	0.11	0.20	0.19	0.00	0.00	0.00
Complex									
NP (P_2O_5)	0.03	1.20	1.15	6.65	6.05	6.15	0.01	1.32	2.52
PK (P_2O_5)	3.72	1.91	1.03	0.00	0.00	0.00	0.00	0.00	0.00
NPK (N)	6.44	6.55	5.32	7.95	4.31	4.33	0.03	0.15	1.41

notes: 1. Data for 1973 used, the first year for which detailed data were available

3C. Packaging

In Western Europe, steel packaging for food in Western Europe was assumed at 71% of all steel packaging, based on (EC, 2001) which attributed 50% to human/pet food, plus 18% to beverage cans, and 6% of closures of which half was assumed to be used in food related products. For aluminium packaging, 78% is attributed to food, based on data from Alupro (2007) and assumptions that 100% of drink cans, 50% of the following categories are used for food: ‘foil trays, lidding, chocolate foil’, ‘aerosols, closures, food cans’ and ‘composite packs’. 40% of paper packaging was assumed to be used for food (based on confidential estimate), 54% of plastic packaging (AMPE, 1997 from EC, 2001), and 95 % from glass packaging (EC, 2001).

In the USA, Table A3.3 gives the shares allocated to food.

Table A3.3: Food packaging allocation in the USA

		% of packaging allocated to food
Paper and board	Corrugated boxes	28[1]
	milk cartons	100
	folding cartons	50
	other paperboard packaging	50
	bags and snacks	50
	wrapping papers	0
	other paper packaging	0
Glass	beer and soft drink bottles	100
	wine and liquor bottles	100
	food and other bottles/jars	80[2]
Steel	beer and soft drink cans	100
	food and other cans	
	other steel	
Aluminium	beer and soft drink cans	100
	other cans	
	foil and closures	
Plastics	Soft drink bottles	100
	milk bottles	100
	other containers	50
	bags and snacks	50
	wraps	0
	other plastics packaging	50

Notes: 1. Based on data from AICC, 2007. 2. Based on similar shares for other bottles in Western Europe (EC, 2001).

Table A3.4 shows a comparison of the material shares allocated to food.

Table A3.4: Share of packaging materials allocated to food, by material.

	W Europe	USA
Paper and Paperboard	0.40	0.32
Glass	0.95	0.94
Steel	0.71	0.46
Aluminium	0.78	0.89
Polymers	0.54	0.46

Packaging values have been expressed per unit of weight. This is the most practical way of measuring packaging at a macro-level. However as a functional unit for packaging, weight is less than desirable. For example, a glass bottle and a PET bottle can both perform the same function – holding a given volume of liquid – but the glass container is typically seven times heavier (Bucklow and Butler, 2000) (See also Table A3.4). The values given in kilogramme terms can obscure the extent of packaging growth in terms of the amount of products packaged. However, the environmental impact will not be obscured because the impact is calculated per material.

Table A3.5 shows how the mass required for packaging materials differs depending on density and strength. It shows the volume which can be packed from a given mass of material, relative to glass. In other words, one kg of paper can pack 26 times as much volume as one kg of glass.

Table A3.5: Factors used by Danish EPA in relating packaging mass of various materials. Source: (Calculated from DEPA, 2001)

Paper (flexible fibre-material)	26
Cardboard (non-flexible fibre-material)	10
Plastics (HDPE, LDPE, PP, PS and PET): Blow-moulded Flexible	 10 41
EPS, PVC	10
Aluminium	15
Tinplate/steel	5
Glass	1

<u>3D. Transport</u>

The trends for food transport were calculated from overall freight transport activity. The Figure A3.5 shows these historic trends, distinguishing between the modes. The key trends are the following:

- There has been strong growth in goods transport in the Western Europe and the USA, and very strong growth recently in China.
- Road transport, which has gained in share in all regions, is particularly important in Western Europe, accounting for over 40% of all the tonne-kilometres.
- There has been a general shift away from rail transport (particularly strong in China and Europe) and towards road and sea transport.

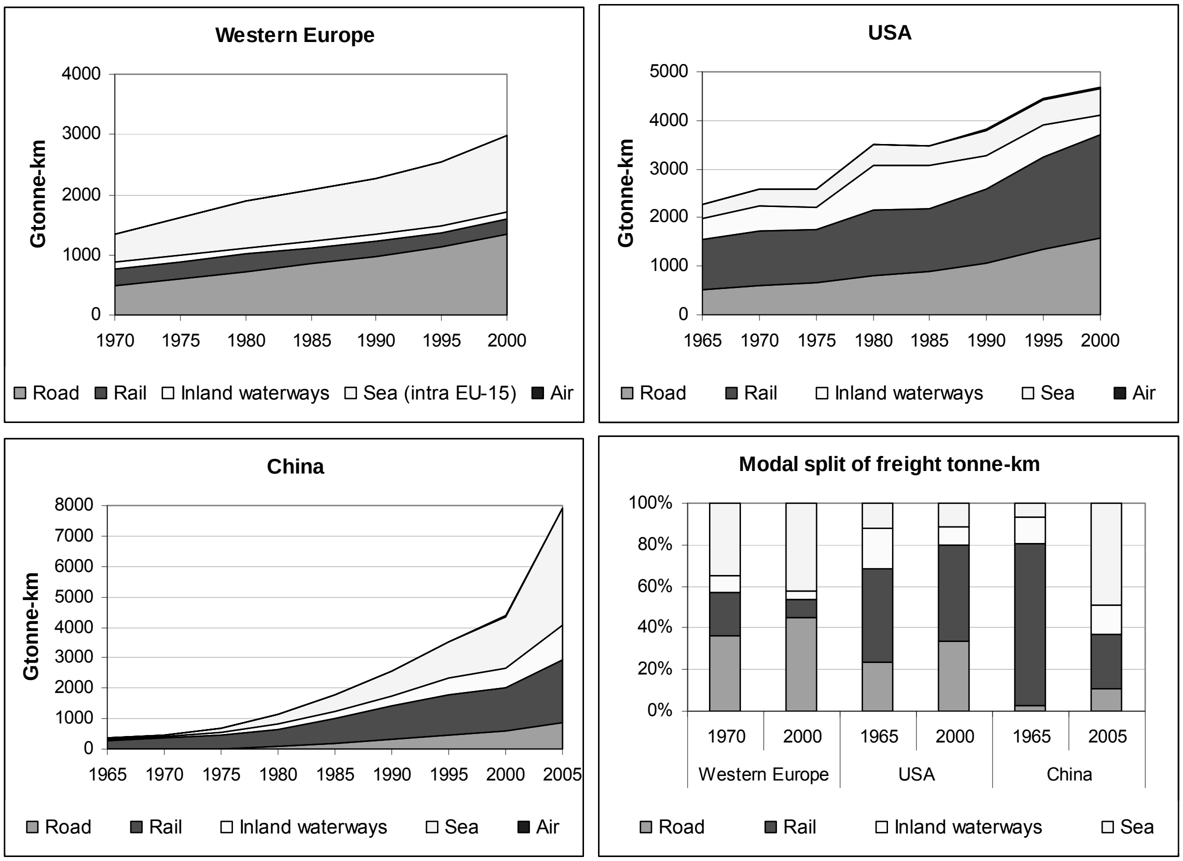


Figure A3.5: Trends in freight transport. Data sources: Western Europe: Eurostat, 2007 and Bosch, 2003; USA: BTS and ESA, 2004; China: NBSC, 2007[58]

Figure A3.6 shows how food commodities differ in modal breakdown from overall freight transport.

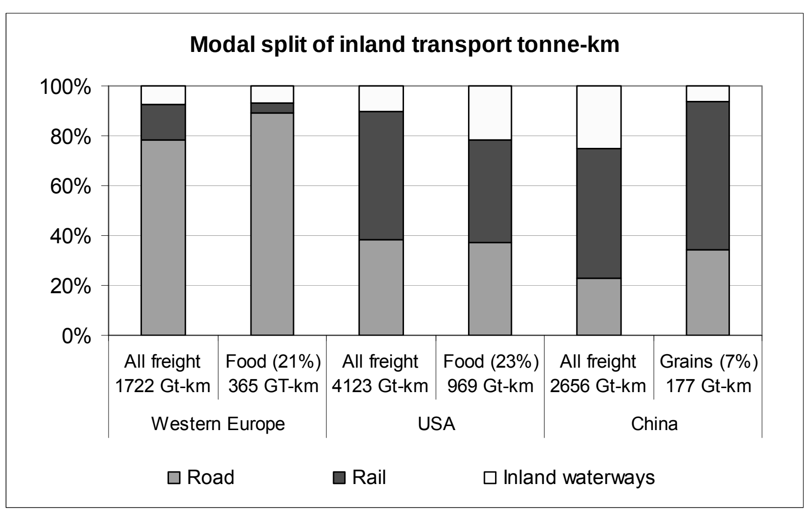


Figure A3.6: Comparison of total freight and food freight transport activity, by mode. Data sources: Western Europe: Eurostat, 2007 and Bosch, 2003; USA: BTS and ESA, 2004; China: NBSC, 2007

Note: For China, only grains (cereals and oilseeds) were known. In Western Europe and the USA, grains account for 14% and 10% of all freight respectively.

[58] Air transport in tonne-kilometers not available for Western Europe

In order to adjust domestic data and trade, the average international shipping distances shown in Table A3.6 was used.

Table A3.6: Weighted average of the distance overseas of food imports [km]. (own calculation)

		1970	1990	2000
Western Europe	Cereals	9200	9000	9200
	Fruit, vegetables and roots	8000	8800	9000
	Sugar	9900	9600	9500
	Oilseeds	9200	9600	9700
	Animal feed	9100	9400	9400
USA	Cereals	6900	8100	8400
	Fruit, vegetables and roots	7800	8200	8000
	Sugar	9200	8100	7900
China	Cereals		12200	12500
	Oilseeds			13600

As a measure of the impact that the trade adjustment made, we calculated the percentage of tonne-km change to domestic transport activity values (negative sign indicates more exports than imports, thus the transport activity allocated to domestic consumption was reduced), shown in Table A3.7. The effect is that the difference between USA and the other regions is reduced.

Table A3.7: Percentage change of domestic tonne-km due to trade adjustment

	1970	1975	1980	1985	1990	1995	2000
W Europe	3.5%	3.1%	3.0%	1.9%	1.7%	1.9%	1.3%
USA	-6.1%	-10.9%	-13.4%	-9.0%	-8.5%	-9.3%	-7.6%
China				-1.2%	1.9%	3.4%	0.3%

The percentage of freight allocated to food varied slightly over the years (see Table A3.8). The assumption that food transported in each mode followed similar growth as overall freight in that mode, caused these differences.

Table A3.8: Percentage of overall freight tonne-km allocated to food

	1970	1975	1980	1985	1990	1995	2000
W Europe	18.5	19.0	19.3	19.8	20.1	20.6	20.6
USA	21.4	22.0	20.2	20.3	21.9	22.0	22.6
China	26.8	25.8	25.5	25.6	25.5	25.3	25.0

Because bulk goods dominate the mass [kg], and thus also the activity [tonne-km], some trends cannot be seen. An example of an obscured trend is that perishable food items, e.g. fruits, vegetables and meat, are more frequently transported longer distances. This has been made possible by transportation technology improvements - especially refrigerated containers with sophisticated climate monitoring systems and containerization, which has resulted in faster handling and made intermodalisation possible – as well as packing improvements and even to some extent bioengineering (Coyle et al., 2001 in Regmi, 2001).

Appendix 4: Product level analysis details

Table A4.1 gives the conversion from processed to raw weights used for the product analysis. The product level analysis calculations were done at the level of FAO FBS availability data, thus the processed food weights were converted using the Table A4.1.

Table A4.1: Weight conversions for product analysis. Source: FAO, 1996 and Wiegmann et al., 2005.

	Raw weight / Processed weight
Wheat Bread	1
Wheat pasta	0.8
Rice	1
Fresh potatoes	1
Frozen/processed potatoes	0.45
All Fresh vegetables	1
All Frozen vegetables	0.77
All Canned vegetables	0.7
All Fresh fruits	1
Fruit juice	0.75
Sugar[1]	1
Oil[1]	1
Beef	1
Pork	1
Chicken	1
Milk	0.9
Cheese	0.15
Highly processed meat	0.8

Note: 1. This is not the conversion back to crop weight, but rather raw sugar and crude vegetable oil. It is different than the factors used for the land use analysis, for which crop weight is necessary.

The remainder of this appendix covers the values used at each stage for the food product analysis. The available datum values from the sources listed in Table 9 are shown here, as well as the averages that were used in this study.

In some cases, energy use was known but not GHG emissions. For transport and processing stages, GHG emissions are due to energy use. To convert energy to GHG emissions at these stages, we used stage specific emission factors, determined from calculations for Western Europe in 2000 (see Section 4.3): 0.074 $kgCO_{2eq}$/MJ and 0.051 $kgCO_{2eq}$/MJ for transport and processing respectively. However, these emission factors were lower than the factors reported for some products. This could be a result of some industrial processes using hydrogen-rich gases, or biomass being used as an energy source. For the agriculture stage, unknown emissions were determined from known energy use by using a specific emission factor calculated for products from the LCA food data (for which both energy and GHG emissions were available).

For the processing stage, only final energy was sometimes available, rather than primary energy. To convert final to primary energy, we assumed 30% of final energy is electricity (if electricity use was not given) (the average for food processing in Western Europe in 2000 from the IEA energy balances), and a conversion efficiency of 40.6% (average of electricity plants in Western Europe in 2000 from IEA energy balances).

Cereals

Wheat bread

Input
Source: LCA food

	Total	transport	processing	agriculture	fertilizer	retail
MJ/kg	6.03	0.85	2.34	0.94	1.76	0.15
%		.14	.39	.45	.29	.02
$kgCO_{2-eq}$/kg	0.932	0.06	0.15	0.42	0.30	0.01
%		.06	.16	.45	.32	.01

Source: Anderson and Ohlsson, 1999 from Foster et al., 2006

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	9.7	3.5	3.9	2.3	-
%		.36	.40	.24	-
$kgCO_{2-eq}$/kg	0.97	0.38	0.21	0.38	-
%		.39	.22	.39	-

Source: Wiegmann et al, 2005
Approximate primary energy for processing (average of five studies): 3.3 MJ/kg (converted from final energy as outlined above). This energy use corresponds to approximately 0.17 $kgCO_{2eq}$ (using the emission factor of 0.051 $kgCO_{2eq}$/MJ given above).

Used in this study:
We used the average of the LCA food, Foster and Wiegmann data for each stage.

	Total	transport	processing	agriculture & fertilizer	Retail
MJ/kg	8.1	2.2	3.2	2.5	.2
%		.27	.40	.31	.02
$kgCO_{2-eq}$/kg	0.95	0.22	0.18	0.55	0.01
%		.23	.19	.58	.01

Pasta

Input
Source: Carlsson-Kanyama, 2001 – for dried pasta from Italy transported to Sweden

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	12.0	3.5	3.6	4.3	0.5
%		.29	.30	.36	.05

The resulting GHG emissions are estimated as follows, based on the energy use:

	Total	transport	processing	agriculture & fertilizer	retail
$kgCO_{2-eq}$/kg	1.60	0.26	0.16	1.15	0.03
%		.16	.10	.72	.02

European Commission (2003, in Ramirez, 2005) reports processing energy use of 0.648 MJ/kg electricity and 0.002 MJ/kg of fuel, or approximately 1.62 MJ/kg primary energy. The GHG emissions were estimated to be 0.155 $kgCO_{2-eq}$/kg using the electricity emission factor from Section 4.3 (Table 12).

Used in this study:

The energy values from Carlsson-Kanyama were used for each stage except processing, where that value was averaged with the Ramirez value.

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	10.9	3.5	2.6	4.3	0.5
%		.32	.24	.39	.05
$kgCO_{2-eq}/kg$	1.53	0.26	0.15	1.15	0.03
%		.23	.10	.65	.02

Note: Other wheat products
Heiss (1996, from Wiegmann, 2005) data show similarity between processing of many wheat products, e.g. cookies, crackers, pastry and wheat/rye bread range from 2.5-3.6 MJ/kg of final product. There are some products which lie outside this range, e.g. pretzels and knäckebrot, but their consumption is relatively small.

Rice

Input
Source: Carlsson-Kanyama, 1998 - weighted average of rice producing countries.

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	11.4	4.6	1.1	5.1	0.5
%		.41	.10	.45	.04
$kgCO_{2-eq}/kg$	6.4	0.448	0.128	5.824	negligible
%		.07	.02	.91	0

GWP in this study was based on a 20 year time horizon, which is significantly different for methane from the 100 year time horizon used in this study. In the 20 year horizon, methane is assigned 2.7 times more global warming potential than in the 100 year horizon. To adjust for this discrepancy, we first separated the expected methane emissions in agriculture by subtracting the carbon dioxide emissions, which we assume is equivalent to wheat production (for pasta), 1.15 $kgCO_{2-eq}/kg$. The remaining 4.67 $kgCO_{2-eq}/kg$ was assumed to come from methane. This was then divided by 2.7, the factor relating the time horizons, which gives an approximation of the equivalent CO_2 emissions due to methane with a 100 year time horizon. The resulting GHG emissions for the agriculture and fertilizer stage, including the carbon dioxide and methane emissions, is 2.88 $kgCO_{2-eq}/kg$. This corrected value[59] was used for agriculture and fertilizer in this study, together with the rest of the above table (see the table below).

Used in this study

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	11.4	4.6	1.1	5.1	0.5
%		.41	.10	.45	.04
$kgCO_{2-eq}/kg$	3.46	0.448	0.128	2.88	negligible
%		.13	.04	.83	0

Starchy roots

[59]Using the corrected 100 year time horizon values, the methane emissions due to rice cultivation in Western Europe in 2000 was found to be 9.6 $kgCO_{2-eq}$/cap. This corresponds reasonably well to the value calculated in the system level approach (following the method outlined in Section 4.3.1), after adjusting for trade, of 8.6 $kgCO_{2-eq}$/cap. (Using the 20 year time horizon values the methane emissions from rice was calculated to be 24 $kgCO_{2-eq}$/cap.)

Raw Potatoes

Input

Source: LCA food

	Total	transport	processing	agriculture	fertilizer	retail
MJ/kg	1.59	0.633	0	0.3627	0.3823	0.214
%		0.40	0	0.23	0.24	0.13
$kgCO_{2-eq}/kg$	0.21	0.0416	0	0.09289	0.05911	0.01593
%		0.20	0	0.44	0.28	0.08

Source: Carlsson-Kanyama, 1998 and Carlsson-Kanyama, 2001

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	2.1	0.7	0	1.1	0.3
%		.35	0	.53	.13
$kgCO_{2-eq}/kg$	0.17	0.0527	0	0.0697	0.0374
%		.31	0	.41	.22

(sorting and packing is assumed to be part of the agriculture stage)

Used in this study:

We used the average of the LCA food and Carlsson-Kanyama data for each stage.

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	1.9	0.7	0	0.9	0.3
%		.37	0	.47	.16
$kgCO_{2-eq}/kg$	0.19	0.047	0	0.111	0.027
%		.25	0	.60	.15

(Frozen) processed potatoes[60]

Input

We use data from Carlsson-Kanyama, to scale up the total energy values, while holding the values of the transport and agriculture/fertilizer stages constant (after using a mass conversion from 1 kg raw potato to 0.5 kg frozen potato (FAO, 2000)), and allocating 90% of the balance to processing and 10% to storage. Carlsson-Kanyama report 6.9 times as much energy use per kg of product for frozen processed potatoes compared to raw potatoes, excluding the household stage. The GHG emissions from processing are assumed to arise from energy use only, therefore the energy values were multiplied by a factor of 0.05 to calculate the GHG emissions (consistent with the ratio calculated from IEA energy balances and IPCC conversion factors for food processing in EU-15 in 2000). We assumed that frozen storage adds an additional 2.2 MJ/kg (1.3 * 1.72 MJ_{final}/kg) to the retail/wholesale stage (from Carlsson-Kanyama, 2001)

Used in this study:

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	13.7	1.4	8.9	1.8	1.6
%		.11	.68	.14	.12
$kgCO_{2-eq}/kg$	1.3	0.09	0.89	0.22	0.15
%		.07	.68	.17	.12

Vegetables

[60] Ramirez reported 5.7 MJ/kg potato product for processing; Wiegmann reports an average value from three studies for frozen French fries much higher, 48 MJ/kg.

Fresh

Input
Average of fresh tomatoes (from southern Europe to Sweden), carrots, and dry peas from Carlsson-Kanyama data was used scale the fresh potato data. Carlsson-Kanyama reported 1.65 times higher energy use for the average of the vegetables than for fresh potatoes.

Used in this study:

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	3.1	1.2	0.0	1.5	0.5
%		.37	.00	.47	.16
$kgCO_{2\text{-}eq}/kg$	0.3	0.08	0.00	0.18	0.04
%		.25	.00	.58	.14

Frozen

Input
Ramirez reports approximately 3.6 MJ/kg for frozen vegetable processing, this added to the fresh energy values after using a mass conversion correction (0.77kg frozen vegetables per 1 kg fresh (Wiegmann, 2006))

Used in this study:

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	9.9	1.5	3.6	1.9	2.8
%		0.15	0.36	0.20	0.29
$kgCO_{2\text{-}eq}/kg$	0.7	0.101	0.180	0.237	0.142
%		0.15	0.27	0.36	0.22

Canned

Input
Wiegmann reports approximately 3.9 MJ primary for canned processing (average of 8 studies and converted to primary energy).

Used in this study:

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	8.4	1.6	3.9	2.1	0.7
%		0.20	0.47	0.25	0.08
$kgCO_{2\text{-}eq}/kg$	0.6	0.11	0.20	0.26	0.06
%		0.18	0.31	0.41	0.10

Fruits

Fresh

Input
Average of apples, oranges, and bananas were used to scale the total energy and GHG emissions in the same manner as vegetables. For the stages, transport represents a larger share for fruits than it is does for potatoes. The average agricultural value from ten studies (in Carlsson-

Kanyama and Faist, 2001) was input for the agriculture stage, with the remainder allocated to transport.

Used in this study:

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	4.9	2.8	0.0	1.3	0.8
%		0.58	0.00	0.26	0.16
$kgCO_{2\text{-}eq}/kg$	0.44	0.21	0.0	0.16	0.1
%		0.49	0.00	0.36	0.16

<u>Juice</u>

Input
Ramirez reports approximately 1.5 MJ/kg for juice processing.

Used in this study:

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	8.0	3.8	1.5	1.7	1.0
%		0.47	0.19	0.21	0.13
$kgCO_{2\text{-}eq}/kg$	0.66	0.28	0.08	0.21	0.09
%		0.43	0.12	0.31	0.14

Sugar/sweetener

<u>Sugar</u>

Input
Source: LCA food

	Total	transport	processing	agriculture	fertilizer	retail
MJ/kg	13.7	2.4	7.7	1.2	1.3	1.1
%		0.18	0.57	0.08	0.09	0.08
$kgCO_{2\text{-}eq}/kg$	1.26	0.16	0.62	0.23	0.18	0.08
%		0.12	0.49	0.18	0.14	0.06

Ramirez reports approximately 6.7 MJ/kg for refined sugar processing.

Used in this study:
Average of Ramirez and LCA food for processing, and the latter for the other stages.

	Total	transport	processing	agriculture	fertilizer	retail
MJ/kg	13.2	2.4	7.2	1.2	1.3	1.1
%		.18	.55	.09	.10	.08
$kgCO_{2\text{-}eq}/kg$	1.23	0.16	0.58	0.23	0.18	0.08
%		.13	.47	.19	.15	.07

Oil

Input Source: LCA food for rape oil

	Total	transport	processing	agriculture	fertilizer	retail
MJ/kg	7.1	1.2	0.5	1.7	2.6	1.1
%		0.17	0.07	0.24	0.37	0.15
$kgCO_{2\text{-}eq}$/kg	1.25	0.05	0.07	0.63	0.42	0.08
%		0.04	0.05	0.50	0.34	0.06

Note: Allocation of co-products was based on economic value

Ramirez reports processing energy use of 0.67 MJ/kg.

Used in this study:

	Total	transport	processing	agriculture	fertilizer	retail
MJ/kg	7.2	1.2	0.6	1.7	2.6	1.1
%		0.17	0.08	0.23	0.36	0.15
$kgCO_{2\text{-}eq}$/kg	1.26	0.05	0.08	0.63	0.42	0.08
%		0.04	0.06	0.50	0.33	0.06

Note: <u>Other oils</u>
Rape and soy oil are similar in their environmental impacts: less than 7% difference in energy use according to Shonfied and Dumelin (2006 in Foster, 2006) and Carlsson-Kanyama, (although (for Western Europe) transport will make up a larger share for soy, as it is imported).

Meat

<u>Beef</u>

Beef and milk are often co-products. The environmental impacts have been allocated between the two as follows: The impact for beef was determined from farms producing beef only. The impact for milk, in which some beef is also produced, was determined by subtracting the impact of an equivalent amount of beef from the total impact of beef and milk.

Input
Source: LCA food

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	52.5	1.2	3.6	47.7	0.1
%		0.02	0.07	0.91	0.00
$kgCO_{2\text{-}eq}$/kg	34.00	0.08	0.66	33.26	0.01
%		0.00	0.02	0.98	0.00

Source: Foster (2006) and Williams et al. (2005) (the former for processing and the latter for agriculture), and subtracting from agriculture and fertilizers an estimated 0.7MJ for feed processing and 0.6 MJ for feed transport, which was included in the Williams study for primary production (0.6 and 0.7 MJ are values from the LCA food study).

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	30.6	-	4.2	26.4	-
%			.14	.86	-

Furthermore, Williams reports 15.8 $kgCO_{2\text{-}eq}$/kg for agriculture and fertilizers.

Ramirez reports processing energy use of approximately 1.4 MJ/kg (not including feed processing, which accounted for 0.7MJ/kg in LCA food).

Used in this study:

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	41.7	1.2	3.3	37.1	0.1
%		.03	.08	.89	.00
$kgCO_{2\text{-}eq}$/kg	25.23	0.08	0.61	24.53	0.01
%		.00	.02	.97	.00

<u>Pork</u>

Input
Source: LCA food

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	16.6	2.2	3.9	10.4	0.1
%		0.13	0.24	.63	.00
$kgCO_{2\text{-}eq}$/kg	3.15	0.15	0.43	2.56	0.01
%		0.05	0.14	0.81	0.00

Ramirez reports processing energy use of approximately 2.1 MJ/kg dressed carcass (compared to 2.0 MJ from the LCA food after feed processing has been deducted).

Cederberg, (2003 from Foster) reports approximately 20.0 MJ/kg and 4.23 $kgCO_{2\text{-}eq}$ for agriculture and fertilizer stage (after deducting estimated feed transport and feed processing).

Williams reports approximately 13.5 MJ/kg and 6.19 $kgCO_{2\text{-}eq}$ for agriculture and fertilizer stage (also after deducting estimated feed transport and feed processing).

Used in this study:

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	20.8	2.2	3.9	14.6	0.1
%		0.11	0.19	0.70	0.00
$kgCO_{2\text{-}eq}$/kg	4.92	0.15	0.43	4.33	0.01
%		0.03	0.09	0.88	0.00

<u>Chicken</u>

Input
Source: LCA food

	Total	transport	processing	agriculture	fertilizer	retail
MJ/kg	20.3	1.9	4.5	11.0	2.9	0.1
%		0.09	0.22	0.54	0.14	0.00
$kgCO_{2\text{-}eq}$/kg	3.42	0.13	0.55	2.27	0.46	0.01
%		0.04	0.16	0.67	0.14	0.00

Ramirez reports processing energy use of approximately 3.1 MJ/kg dressed carcass
(not including feed processing which accounts for 1.9 MJ and transport which accounts for 1.2 MJ in LCA food).

Williams reports approximately 8.9 MJ/kg and 4.43 $kgCO_{2-eq}$ for agriculture and fertilizer stage (after deducting estimated feed transport and feed processing).

Used in this study:

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	16.8	1.9	4.8	10.0	0.1
%		0.11	0.29	0.60	0.01
$kgCO_{2-eq}$/kg	4.08	0.13	0.59	3.35	0.01
%		0.03	0.14	0.82	0.00

Processed meat

Input

Ramirez reports processing meat products energy use of approximately 5.8 MJ/kg processing, which is approximately 3.4 MJ/kg in excess of minimally processed meat (including beef, pork and chicken, based on weighted average of W Europe in 2000).

Weigmann averages for sausage are very close (within 5% after estimating primary energy). Note: this is based on product weight, whereas the rest of the meat category is based on dressed carcass weight.

Dairy

Milk (drinking)

Input

Source: LCA food

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	3.9	0.9	0.8	2.1	0.1
%		0.23	0.22	.54	.01
$kgCO_{2-eq}$/kg	0.93	0.06	0.06	0.81	0.00
%		0.06	0.06	.87	.00

Source: Foster et al. (middle values within range) and UNEP, 2001 (for processing)

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	4.4	0.9	1.0	2.4	0.1
%		.20	.23	.54	.02

Note: after subtracting for 0.6MJ/kg feed transport.

Foster et al., 2001 report that energy use of primary production (which is mostly agriculture and fertilizer, but also includes small amounts of energy for processing and transport of animal feed) is 2.5-3.5 MJ/kg, 1.0 MJ/kg processing, 0.1-0.5 MJ/kg transport, and 0.1 MJ/kg retail[61].

Ramirez reports processing energy use of approximately 1.1 MJ/kg.

Used in this study

[61] actually per liter, but the density of milk is approximately 1 kg/l

The GHG emissions corresponding to the energy reported by Foster/UNEP were estimated from emission factors ($kgCO_{2eq}$/MJ) according to LCA food results. The average of the two were used in this study.

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	4.3	0.9	1.0	2.3	0.1
%		.14	.23	.60	.02
$kgCO_{2-eq}$/kg	1.09	.06	.08	0.95	0.00
%		.06	.07	.87	.00

<u>Cheese</u>

Input

Source: LCA food (with whey designated as by-product)

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	34.6	3.0	12.1	19.4	0.1
%		0.09	0.35	.56	.00
$kgCO_{2-eq}$/kg	8.43	0.20	0.77	7.46	.01
%		0.02	0.09	.88	.00

Ramirez reports processing energy use of approximately 5.1 MJ/kg cheese; Foster reporting 37.5 MJ/kg in agriculture and fertilizers and 8 MJ/kg (middle value) for processing.

Used in this study

	Total	transport	processing	agriculture & fertilizer	retail
MJ/kg	40.0	3.0	8.4	28.5	0.1
%		.08	.21	.71	.00
$kgCO_{2-eq}$/kg	11.74	.20	0.53	11.0	0.01
%		.02	.05	.94	.00

Appendix 5: System level analysis details

5A. Agriculture

Tables A5.1 and A5.2 show inputs used for calculating the GHG emissions from agriculture. The weighted factors for manure are an estimate of the relative GHG emissions impact of different types of livestock manure for the different regions (taking into account factors such as climate and animal breeds). Figure A5.1 shows the resulting emissions from the various sources at this stage according to the system analysis.

Table A5.1: Physical flows used for determining agricultural GHG emissions. Sources: FAOSTAT, 2007 and IFA, 2007

	W Europe			USA			China			
	1970	**1990**	**2000**	**1970**	**1990**	**2000**	**1970**	**1990**	**1994**	**2000**
# cattle (millions of heads)	91	92	83	112	96	98	58	79	91	105
# livestock (millions of heads - cattle eq.)	155	179	170	197	176	186	92	185	206	225
Mt N fertilizer	7.1	10.4	9.4	7.4	10.2	10.5	3.0	19.2	19	22.7
Mt rice produced	2	2	2	4	7	9	113	192	190	178

Table A5.2: Weighted factors for manure. Source: Steinfeld et al., 2007

		W Europe	USA	China
	dairy cattle	41.8	51	12.9
	other cattle	10.9	9.5	1
	pigs	11.1	22.7	7.6

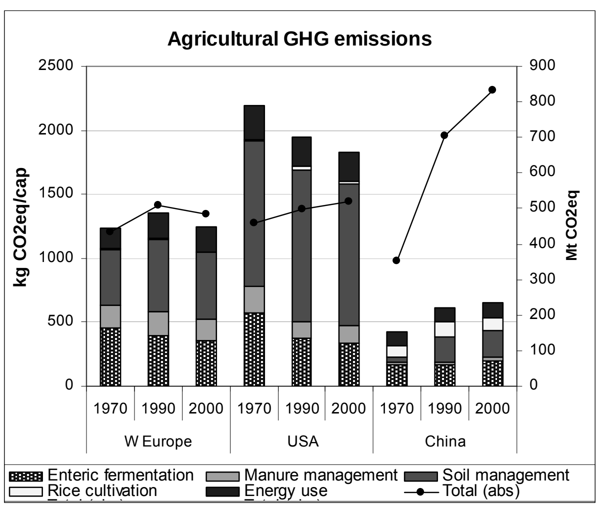


Figure A5.1: GHG emissions due to agriculture

5B. Transport

As explained in Section 4.3.3, food transport energy use was calculated by multiplying transport activity [tonne-km] by the specific energy use, then calibrated. The calibration of transport energy use with IEA values was done in the following manner. The specific energy use values for freight transport were multiplied by the activity for freight, for each mode. Likewise, the specific energy use values for passenger transport were multiplied by the activity for passenger transport [in passenger-km], also by mode. The passenger freight data were available from the same sources as freight data (i.e. Eurostat, 2007; Odyssee, 2001; BLS, 2007; EERE, 2007). Because of data availability this could only be done for the USA and Western Europe, and for road and rail modes. These values were summed, generating the total transport energy use by mode comparable with IEA values. The percentage by which these values differed was considered to be due to inconsistencies the specific energy use values, thus these were adjusted accordingly. For example, Western European total road transport energy use was calculated to be 87% of the energy use according to the IEA. Thus, instead of using a specific energy use of 3.0 MJ/tonne-km, we used the calibrated 2.6 MJ/tonne-km (3.0 multiplied by 0.87). The calibration factors are shown in Table A5.3. As seen in Figure A5.2, road energy use dominates, thus the specific energy use values for other modes will have a minor impact.

Table A5.3: Transport calibration factors (ratio of calculated transport energy use over IEA energy use)

	W Europe			**USA**		
	1970	**1990**	**2000**	**1970**	**1990**	**2000**
Road	0.87	0.98	1.01	1.03	1.01	1.04
Rail	0.83	0.46	0.43	0.97	0.98	0.79

It should be noted that the specific energy use values in the literature were calculated (by the original authors) using different methods. For Western Europe and the USA, the specific energy use for freight, as reported in the Odyssee database (2001) and EERE (2007), was the outcome of allocating fuel use among freight and passenger vehicles, the freight portion was then divided by the tonne-km For China, the specific energy use was calculated in a different manner. Skeer and Wang (2007) determined it by combining the freight tonne-km with equivalent tonne-km from passenger travel, equalling the total equivalent tonne-km. The known transport energy use, per fuel, was then divided by the total equivalent tonne-km in each mode.

The energy use and GHG emissions due to food transport is shown in Figure A5.2. The impact from road transport dominates by far – 80% of the total transport impact for Western Europe and the USA in 2000, despite accounting for less than 40% of the tonne-km. Inspection of the differences in specific energy use show clearly why this is the case – road transport generally is on order of magnitude more energy intensive than rail or water. The growing modal share of road transport is a major cause for increasing transport energy use in all regions.

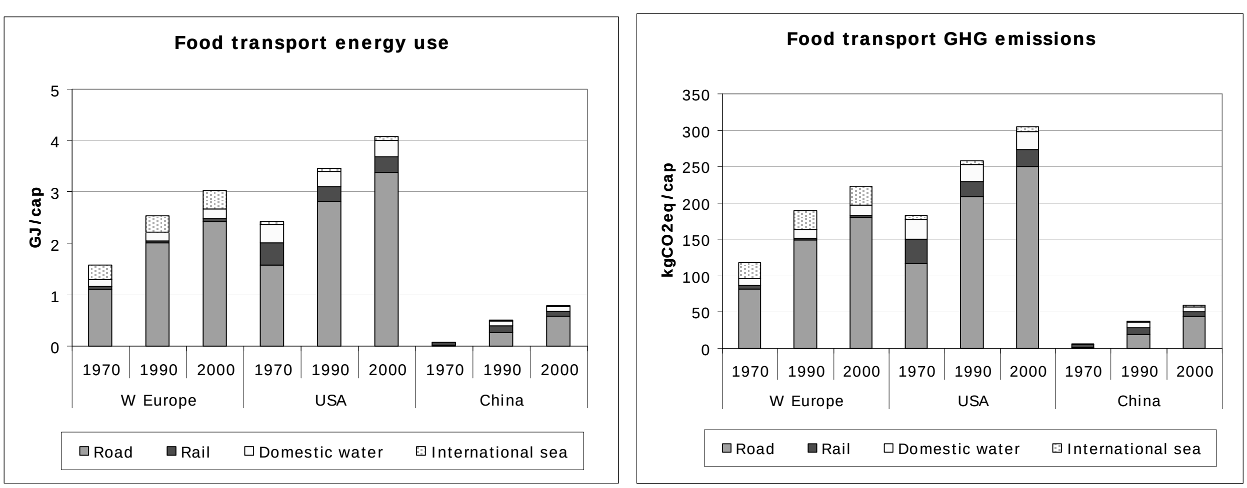


Figure A5.2: Energy and GHG emissions during transport, by mode.

5C. Packaging

Table A5.4 shows the results of a Danish Environmental Protection Agency (DEPA, 2001) study of packaging energy use. These values include can be compared with Table 17 (Section 4.3.4), although the DEPA values include the waste management stage, whereas those from Table 17 do not.

Table A5.4: Primary energy consumption of packaging (MJ/kg) according to DEPA, 2001

Waste management:	Incineration		Recycle	
Raw material:	Primary	Secondary	Primary	Secondary
Paperboard	22.3	25.2	17.7	17.0
Glass				8.0
Polymers				
HDPE	52.7	37.7	38.0	36.5
LDPE	60.0	43.6	40.1	30.4
PP	55.9	36.9	37.9	36.4
PS	73.9	55.2	46.5	41.6
EPS	96.7	71.2	42.2	39.7
PET	67.2	51.0	40.5	38.9
PVC	60.0	47.4	36.6	35.3
Steel (tin plate)	35.7		29.0	
Aluminium	153.9		47.9	

Figure A5.3 shows the breakdown of energy and emissions by material.

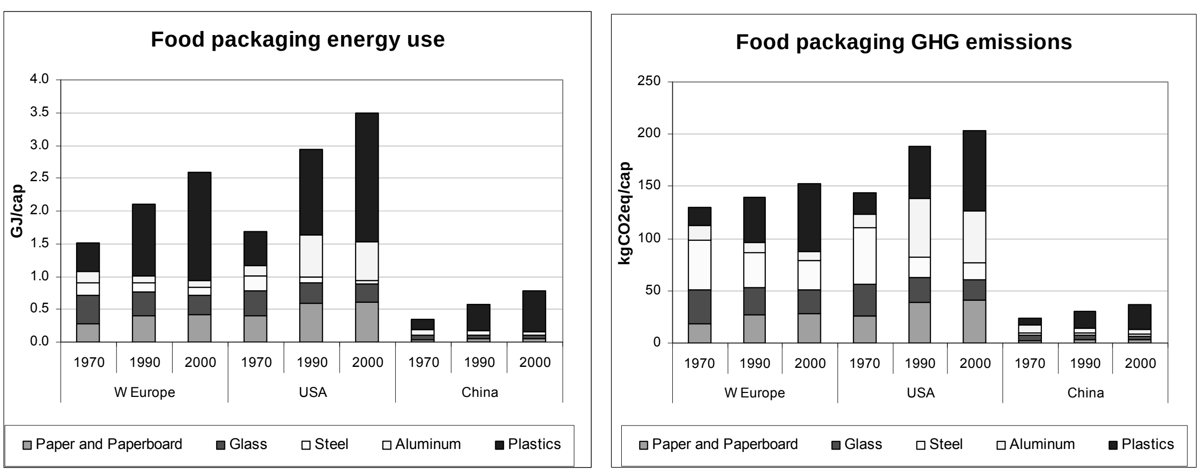


Figure A5.3: Energy and GHG emissions during packaging, by material

5D. System level totals

Table A5.5 shows the results of all stages of the system level analysis.

Table A5.5: Results from the system level analysis

		W Europe			USA			China		
		1970	**1990**	**2000**	**1970**	**1990**	**2000**	**1970**	**1990**	**2000**
Energy use GJ/cap	Transport	1.6	2.5	3.0	2.4	3.5	4.1	0.1	0.4	0.8
	Packaging	1.5	2.1	2.6	1.7	2.9	3.5	0.4	0.6	0.8
	Ag and Fert	3.8	4.5	4.2	5.7	4.9	4.6	1.2	2.1	2.3
	Processing	3.0	3.6	3.9	3.4	4.7	5.4	0.8	0.8	0.6
GHG emissions kgCO2eq/cap	Transport	120	190	220	180	260	300	10	40	60
	Packaging	130	140	150	140	190	200	20	30	40
	Ag and Fert	1450	1520	1370	2400	2090	1950	410	650	700
	Processing	230	210	200	250	330	350	80	80	60

Appendix 6: Scenario details

Figure A6.1 shows the trajectories of food consumption scenarios for some of the major categories. For the bovine, pig and poultry meat categories, the FAO did not make projections apart from the meat category as a whole. The values in Scenario 1A for bovine, pig and poultry meat are our own estimates based on the availability trends, which in sum equal the FAO projections for the meat category. Also, for fruits and vegetables, no projections were made by FAO or IC2, thus the scenarios represent our own projections based on the time series data and our judgement.

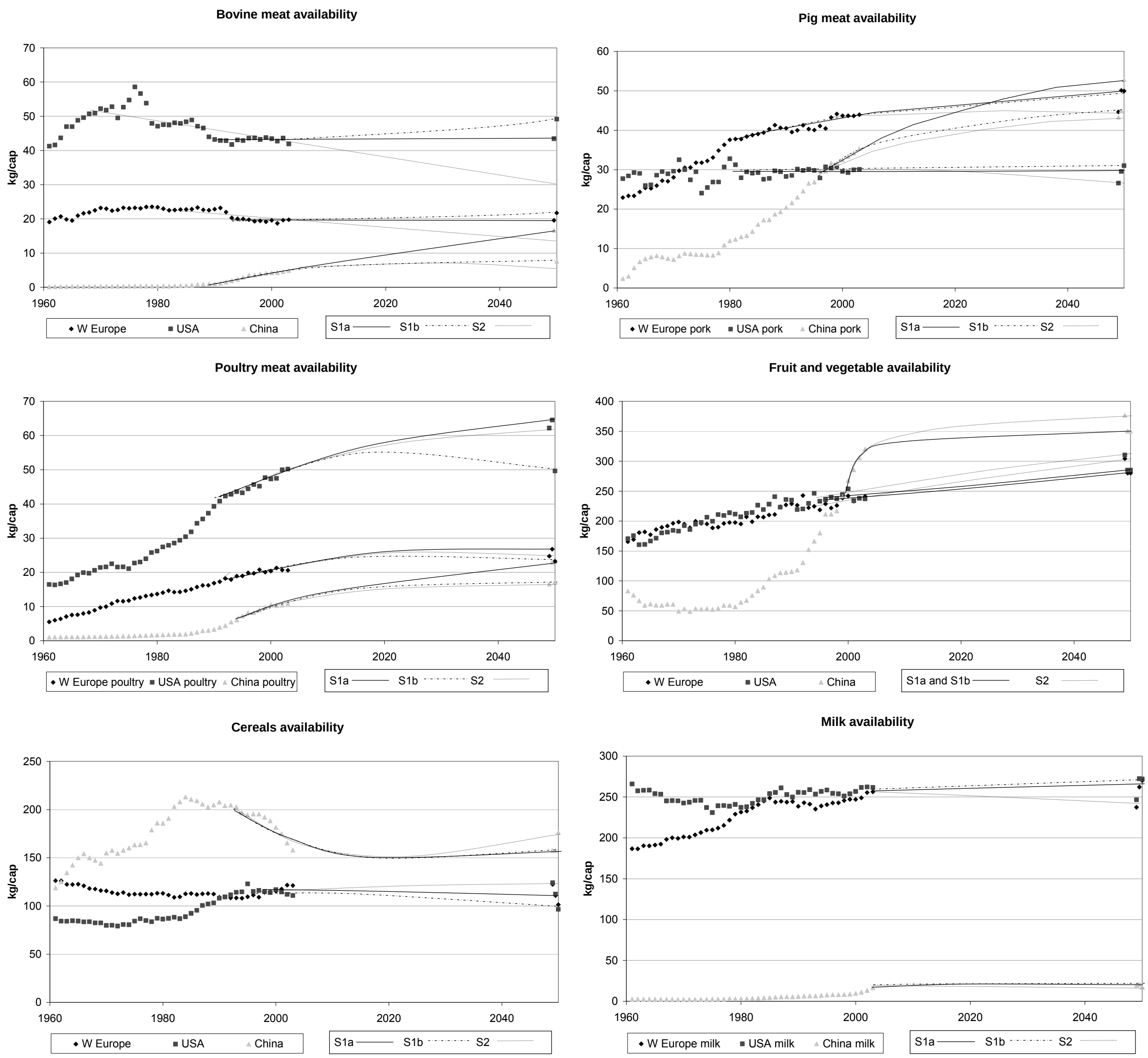


Figure A6.1: Food category availability for the future scenarios

Table A6.1 shows the relative differences in energy use for each food category in 2000 (and assumed for 2050). Note that the variation is greater in agriculture and fertilizers than transport and processing.

Table A6.1: Relative energy use of various food categories compared to the average, by stage, in 2000

	Agriculture and fertilizers			Transport			Processing		
	W Europe	USA	China	W Europe	USA	China	W Europe	USA	China
cereals excl. rice	0.7	0.5	1.6	1.5	1.5	1.8	1.5	1.2	2.6
rice	1.3	0.9	2.0	3.1	3.1	2.3	0.5	0.5	1.7
roots	0.2	0.2	0.4	0.5	0.5	0.4	0.5	0.8	0.0
vegetables	0.4	0.3	0.6	0.8	0.8	0.6	0.3	0.5	0.2
fruits	0.3	0.2	0.5	1.9	1.9	1.4	0.1	0.2	0.0
sugar	0.6	0.5	1.0	1.6	1.6	1.2	3.6	3.0	11.1
oil	1.1	0.8	1.7	0.8	0.8	0.6	0.3	0.2	0.9
beef	9.2	6.9	14.4	0.8	0.8	0.6	2.5	2.0	5.8
pork	3.6	2.7	5.7	1.5	1.5	1.1	2.8	2.3	6.7
poultry	2.5	1.9	3.9	1.3	1.3	1.0	3.2	2.7	8.1
other meat	4.6	4.7	-	1.3	1.1	-	2.8	2.2	-
milk	0.8	0.5	0.8	0.4	0.5	0.4	0.7	0.5	1.4
other / average	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Table A6.2 corresponds to Table 23, but is expressed per capita rather than per kg of food.

Table A6.2: Per capita index of structural activity change

	Activity level per capita in 2050 (indexed to 1.00 in year 2000)			
Stage	W Europe	USA	China	unit
Agriculture	1.07	1.06	1.19	kg food / cap
Fertilizers	.59	.52	.80	kg nutrient / cap
Transport	1.86	1.29	2.06	ktonne-km / cap
Processing	2.57	2.40	12.49	GDP(PPP) / cap
Packaging	1.01	.99	2.10	kg material / cap

Table A6.3 contains projections for energy use for fertilizer production in 2050. The share of N:P:K fertilizers in each region is tending towards 6:2:2, which was used to approximate the nutrient mix. GHG emissions by source followed the changes in main physical flows, given in Table A6.4.

Table A6.3: Average fertilizer energy requirement [MJ/kg]

		1970	1990	2000	yearly index of change (1970-2000)	2050 S1a	2050 S1b	2050 S2	2050 S3
W Europe	N[1]	55	40	35	0.985	27	27	27	26
	P	16	14	13	0.994	9	9	9	8
	K	18	14	13	0.990	8	8	8	7
	Total	33	28	26	0.992	13	13	13	12
USA	N[1]	46	40	36	0.991	27	27	27	26
	P	21	13	11	0.980	4	4	4	4
	K	20	12	11	0.981	4	4	4	4
	Total	34	28	25	0.990	16	16	16	14
China	N[1]	60	50	44	0.989	27	27	27	26
	P	16	13	14	0.996	11	11	11	12
	K	15	8	13	0.995	10	10	10	9
	Total	50	41	33	0.986	20	20	20	18

note: 1. The theoretical minimum for producing ammonia, the building block of all N-based fertilizers, from natural gas is 23.3 MJ/kg N (Ramirez, 2005). The regions are assumed to come no closer than 15% of this minimum under the baseline energy efficiency scenario and 10% under the alternative.

Table A6.4: Projections of physical flows for agriculture in 2050. Indexed to 1.00 in 2000.

	W Europe				USA				China			
	S1a	**S1b**	**S2**	**S3**	**S1a**	**S1b**	**S2**	**S3**	**S1a**	**S1b**	**S2**	**S3**
cattle	1.03	1.10	0.83	1.03	1.03	1.10	0.83	1.03	3.02	1.77	1.72	3.02
cattle eq.	1.09	1.12	0.93	1.09	1.00	1.06	0.85	1.00	2.05	1.64	1.35	1.46
N fert.	0.74	0.74	0.74	0.74	0.86	0.86	0.86	0.86	1.10	1.10	1.10	1.10
rice	0.96	0.90	0.86	0.96	0.96	0.85	0.86	0.96	0.87	0.98	0.77	0.87

Table A6.5 shows the average annual yield (or land requirement) improvements assumed for the land use scenario projections.

Table A6.5: Average annual yield improvement [%/yr]

	W Europe		USA		China	
	1970-200	2000-2050	1970-200	2000-2050	1970-200	2000-2050
Cereals	2.37	0.59	2.04	0.51	2.62	0.66
Roots and Tubers	1.73	0.43	1.71	0.43	1.11	0.28
Vegetables	1.49	0.37	1.87	0.47	0.84	0.21
Fruit	0.61	0.15	1.27	0.32	1.76	0.44
Sugar crops	1.56	0.39	-0.05	-0.01	1.15	0.29
Oilseeds	0.65	0.16	1.33	0.33	1.98	0.49