Energy 37 (2012) 115–121

Contents lists available at SciVerse ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Global food supply and the impacts of increased use of biofuels

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ARTICLE INFO

Article history:
Received 2 February 2011
Received in revised form
5 September 2011
Accepted 9 September 2011
Available online 14 October 2011

Keywords:
Food
Feed
Biofuels
Food security
Global food markets

ABSTRACT

In recent years prices on global food markets showed large fluctuations. The use of biomass as energy source (biofuel) in the developed world is frequently mentioned as one of the reasons for this instability. This paper compares the need for biofuel and needs for food and feed on global scale. A simple model is developed to estimate present and near future global needs for food, livestock feed and energy. We distinguish between developing countries, transition countries and the developed countries. The first group of countries needs extra food for their growing population, the second one needs extra feed, since the increased incomes among their population lead to increased demands for animal products. The developed countries require biomass to reduce the CO_2 emissions of their energy use. On global scale the extra needs for biomass as a fuel (1100 MT) turn out to be larger than the extra needs for food and feed (800 MT each). At present the developed countries are food exporters, their produce is essential for several food insecure countries in Africa and Asia. The increased need for biomass for energy is likely to affect these exports and therefore affect food security in parts of the world.

1. Introduction

Three years ago (2008) world market food prices reached highest levels ever, leading to increased costs for food and food security problems in the third world. Food and Agricultural Organization (FAO) reported food riots in 33 countries and estimated that 75 million people became food insecure over and above the 850 million in the years before. Later that year food prices dropped again and they remained relatively low for two years but in spring 2011 prices on global markets rose again and reached the 2008 levels [1]. In FAO and Organization for Economic Co-operation and Development (OECD) publications the increased use of cereals as feedstock for biofuel is mentioned as one of the causes for the price rises on the global food markets [2,3]. However analysis from Trostle [4] showed that more factors played a role: increasing demand due to increasing population and increased meat consumption per capita, slowing growth of agricultural production, declining demand for stocks, rising energy prices, rising farm production costs, adverse weather in production areas, export restrictions, aggressive purchases by importers and speculation.

The increased demand for biofuels in OECD countries is the result of Climate Policies developed in these countries [2]. Energy from biomass is considered to be climate neutral and in many national climate policy plans the use of biomass as energy source plays an important role. These policies are based on publications from organizations like the International Energy Agency (IEA). In these reports biomass is assessed to be a CO_2 neutral energy source that could supply a large share of the global energy needs, without affecting food supply [5]. The present use of biofuels is small (less than 1%). Climate Policies aim at 10% energy from biomass by the year 2020 [6,7] and various incentives exit (blending mandates, subsidies etc.) to achieve these goals [7].

However, since the present very small biofuel use is associated with rising food prices on global food markets and food security problems in Africa and Asia, it is essential to evaluate the possible impacts of increased use of biofuels on global markets to prevent global food security problems in near future. In here we only focus on the demand side and determine present and future needs for food, feed and fuel and compare their order of magnitude. We assume that when need for biomass for fuel is small in comparison with the need for food and feed is not likely that the need for biofuel will have large effects on global food prices. Trostle [4] showed that factors like speculation and local export bans played a role, these type of factors are not taken into consideration in this paper.

We first analyze the present import and export for food and feed on a global scale. We determine total production and consumption quantities and the share of the food that is traded on the global markets. Than we determine the demands for food, feed and fuel in the coming decades and compare the order of magnitude of these demands. With respect to global demands for food three different

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doi:10.1016/j.energy.2011.09.019

factors are of importance: the size of the global population (more people need more food), the type of diet of this population (luxurious diets require more resources than basic menus) and the use of cereals as source for biofuels. These factors show different patterns in time and space. To understand the processes behind these demands the needs for food, feed and energy are first discussed in historical perspective on the global level, then the differences between various countries are analyzed. With this knowledge a very simple model is constructed to determine present and future needs for food, feed and fuel. The model results are compared with the present situation on the global cereal market, and consequences of present Climate Policies in OECD countries for food security in the developing countries will be discussed.

2. Present situation on global food markets

The total global food exports include 950 Mton [8,9]. The largest share is provided by cereals (30% of the total) followed by fruits (7%) and oil crops (5%). The total global annual cereal production involves 2800 Mton [8,9]. Fig. 1 shows the cereal production and consumption in various continents and the imports and exports. The production is highest in Asia and lowest in Africa. Note that continents are more or less self-supporting with respect to cereals; over 90% of the consumption is met with the local production. Only a small fraction (285 Mton (10%)) of the total cereal production is actually sold on the world markets. North America and Europe are producing more than they consume and are exporting, while in Africa and Asia consumption is larger than the production and extra imports are needed. But major share of the food is actually produced on the continent where it is consumed.

The finding that the global cereal market is small in comparison with the total production (10%), and that Asia and Africa are dependent on imports from other continents to feed their population makes that in this paper distinction is made between needs for food, feed and fuel in different continents.

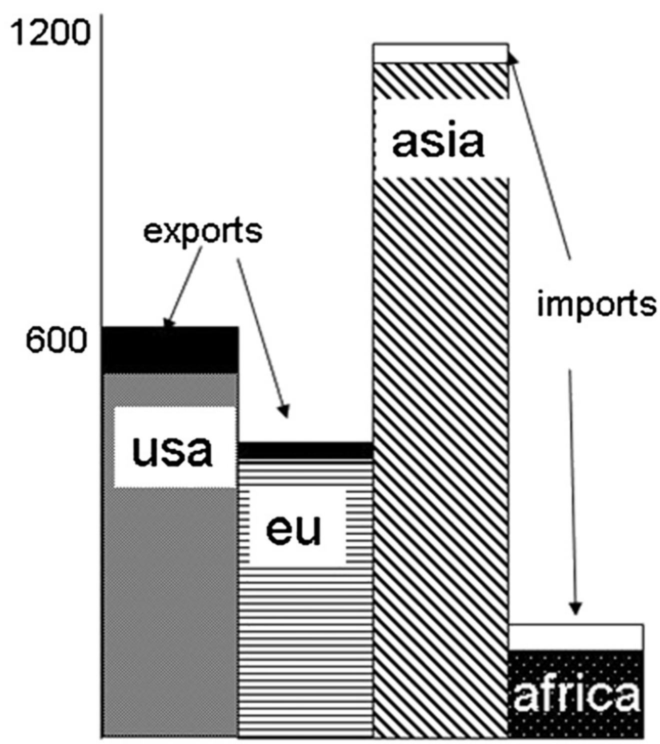

Fig. 1. Comparison between cereal production and consumption, imports and exports in MT for 4 continents (source FAOSTAT [8], see text for explanation).

3. Food demand

The main driver for the global demand for food is the size of the population, increase of the population leads to an increased demand for food. Fig. 2 shows the global population from 1750 onwards based on [10].

In 1750 the global population was less than 1 billion people, it doubled in the next 200 years up to 1950 and from then on a steep increase was observed, it nearly tripled in 50 years. Up to the 2 billion people the increased need for food was fulfilled by increasing the area under cultivation [10]. Later on the green revolution with the improved crop varieties, application of fertilizer and pesticides etc., led to large increases of the crop yields per hectare and area under agriculture remained the same [10].

Presently large differences between individual countries exist with respect to population growth. Fig. 3 shows the population growth per year over the last 15 years for a large variety of countries from very poor countries in Africa to the rich countries in Europe (source [11]). The population growth is plotted against the Gross Domestic Product (GDP) of the country in that particular year (data obtained from Groningen Growth and Development Centre (GGDC) [12]). The GDP is used as indication for the economic development of the countries. The rich countries are on the right hand of the graph and the poor countries on the left hand.

Fig. 3 shows that in the developing countries population growth is around the 2–3% per year, it declines rapidly with increasing GDP and levels of around 1% in the rich western countries. It should be noted that population growth is plotted here, not birth rates. The increase in Ireland over the last 15 years is mainly caused by Irish returning back to Ireland, after having left for the US in the economic crisis in the 1980-ties.

3.1. Demand for meat and livestock feed

Meat consumption plays an important role in global demands for cereals. Presently over 35% of the cereals produced in the world is fed to livestock [13]. Fig. 4 shows the global meat consumption from 1960 onwards based on data from FAO statistics [8]. It distinguishes between developed and developing countries. In the last 50 years annual the meat consumption increased from 70 to 250 MTon per year. In 1960 two thirds of the meat (50 MTon) was consumed in the developed world. This amount increased to 90 Mton in 1990 and remained constant afterward. The consumption of meat in the developing world was 25 Mton in 1960 and increased to 160 Mton in 2010. In contrast to the consumption in the developed world no sign of stabilization in the consumption can be observed.

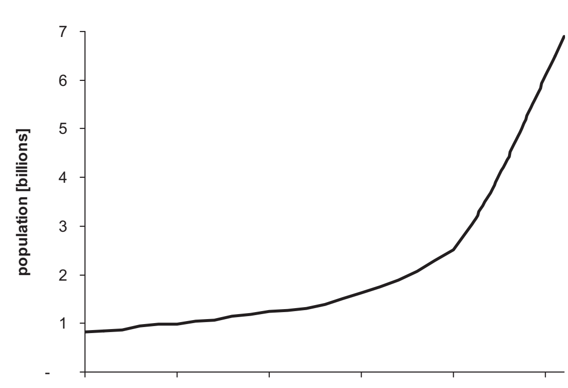

Fig. 2. World population from 1750 onwards (Evans [10]).

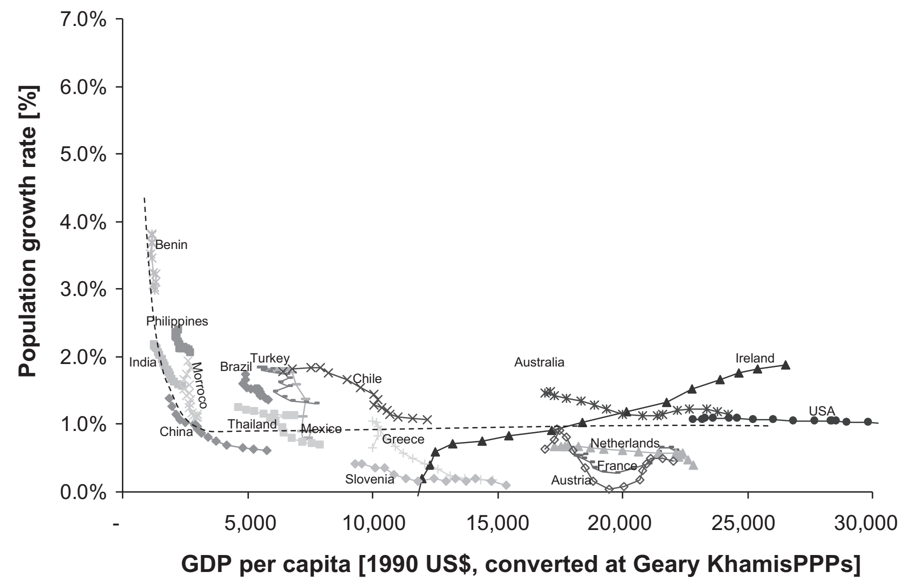

Fig. 3. Population growth as function of GDP per capita. Dotted line shows general pattern used in this paper. (Data are for the years 1990–2005; sources GGDC [12], FAOSTAT [8];).

The feature of stabilizing meat consumption in Western Europe and USA can also be recognized in Fig. 5. This graph shows the changes in consumption of animal origin food products (meat, milk, eggs, fish) over the last 15 years for the same countries as studied in Fig. 3. Data on animal food products consumption are obtained from FAO statistics [8] and are plotted against the GDP of the country in that particular year [12]. The consumption is expressed as percentage of the total calories consumed. Fig. 5 shows that in the developing countries meat consumption is low (5–10%) with rising GDP values the consumption increases fast to 35% of the calories. At GDP values of about 10.000 $ per capita, a saturation level is reached and meat consumption levels remain at this 35%. In the high income countries like USA and Western Europe consumption of animal products actually did not increase over the last 15 years. The largest changes in meat consumption occur in the fast growing economies in Asia (India and China). These countries have GDP values above $2000 per person, and due to the fast economic growth, their GDP is increasing fast. Fig. 5 shows that meat consumption per person in China doubled over the recent 15 years. Poleman and Thomas [14] showed that the relation between GDP and the consumption of animal products holds for many more countries than those in the sample presented here.

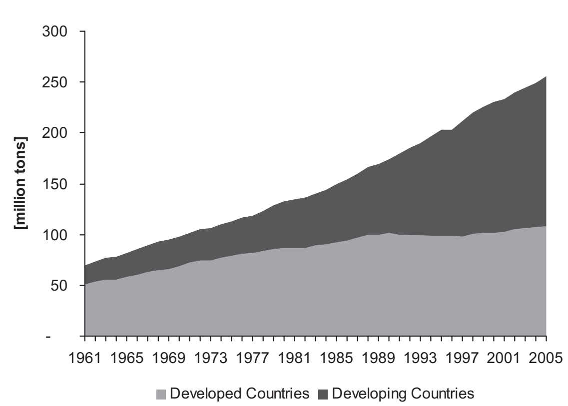

Fig. 4. Trends in global meat consumption (source: FAOSTAT [8]).

4. Energy demand

Fig. 6 shows the development of global energy use since the mid-19th century, both the total consumption as the main energy sources are shown (based on [15] and [16]). Until 1900 the consumption was more or less constant at 20 EJ y^{-1}. After the industrial revolution the total energy use increased to nearly 500 EJ y^{-1}. Besides this enormous increase in total consumption also a change in energy sources is evident. Before the industrial revolution energy consumption was mainly supplied by wood and in present days it is a mix of several energy sources.

Presently coal, oil and gas account for over 90% of the energy use (Fig. 6). These energy carriers are fossil, they originate from plant material produced in ancient times and combustion of these energy sources lead to emissions of CO_2.

In Fig. 7 we show the energy use per capita plotted against GDP for the same countries as in Fig. 3 And 5. Data on energy use are obtained from IEA statistics [17] and GDP values from GGDC [12]. With respect to energy use a more or less linear relation is found between GDP and energy use. The rich countries are requiring nearly 5 times more energy per person as the poor countries. But also large differences between countries at the same level of welfare exits. A person in the USA is using 350 GJ $year^{-1}$, while a person in Ireland, at the same welfare level only needs 200 GJ $year^{-1}$

5. Assessing future food, feed and fuel need in various parts of the world

In the previous paragraphs we described past and present needs for food, feed and fuel in various parts of the world. When studying future needs, one has to realize that the drivers behind changing demands differ between countries. In some countries population growth is large, in some countries there is a strong increase in the demand for meat and in other countries new energy policies are put into practice. We simplify the large variety in welfare throughout the world into three groups: poor people living in developing countries, rich people in Western Europe (EU) and the USA, and people in the so-called transition countries (China, India) showing a fast economic development.

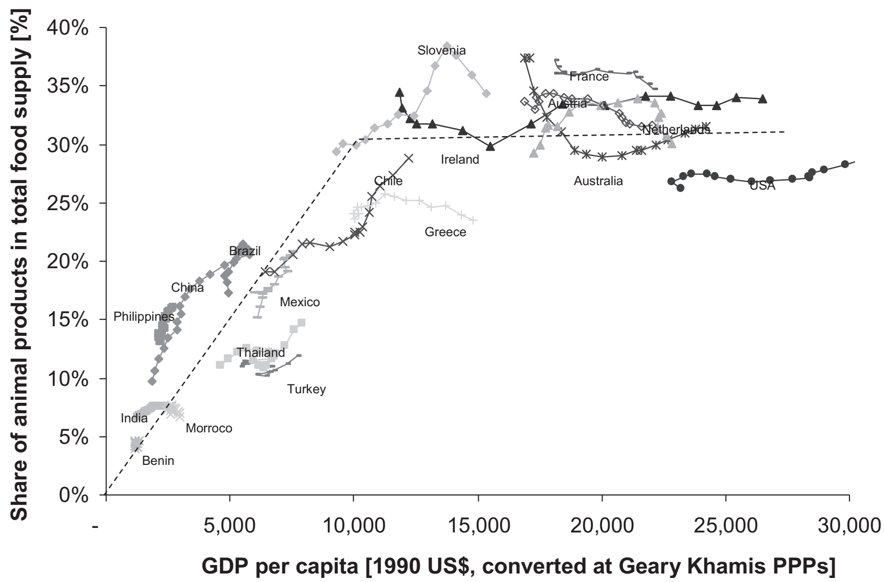

Fig. 5. The relative consumption of animal origin food products (share in total calories consumed) in relation to GDP per capita. The dotted line shows the relation between GDP and consumption of animal products used in this paper. (Data are for the years 1990–2005; sources: GGDC [12]; FAOSTAT, [8]).

In developing countries (GDP up to $ 2000 per capita) consumption of meat and energy is very low, but population growth is large (compare Figs. 3, 5 and 7). This implies that in the coming decades these countries need extra food to fulfill the needs of their growing populations. At present these countries accommodate around 3 billion people [11]. Assuming population growth at 2% (based on data in Fig. 2), this population will increase to 5 billion within 20 years. Since, in these countries, economic development is slow, neither major changes in meat consumption nor an increase in the use of biomass as an energy source is expected.

About 2 billion people are living in the so-called transition countries [11]; these countries show fast economic development with GDP growth rates of around 6% per year [11]. This implies that within 20 years their GDP will increase from around $ 2.000 to $ 10.000 per capita. Following the relation shown in Fig. 5, their animal product consumption will reach saturation levels of around 35% of total calories consumed. This implies that for these countries the needs for livestock feed will increase.

The EU and the US together have about 1 billion inhabitants. In these countries population increase is low and their animal product consumption has reached the saturation levels (Fig. 3 and 5). Therefore no drastic changes with respect to biomass needs for food and feed are to be expected. However, these countries are putting energy policies into place aimed at combating the effects of climate change. Biomass, often considered a carbon neutral energy source

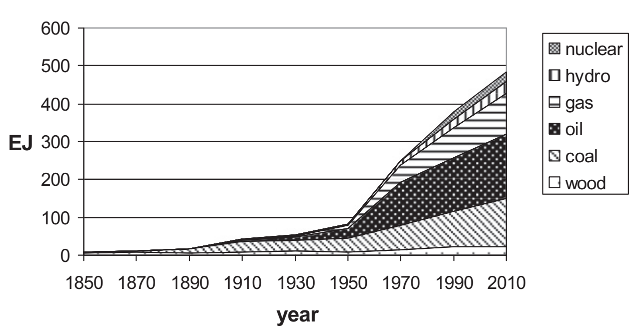

Fig. 6. Development of global primary energy use according to main energy sources 1850–2010; (adapted from Grubler and Nakicenova [15], using data from IEA [16]).

in this context, is playing an important role in these policies. Most policy plans mention a target of 10% of total energy supply from biomass for 2020/2030 [6,7]. Present energy use in developed countries is at 200–400 GJ per person per year. The present policy goals therefore imply that at least 20 GJ per person should be obtained from biomass within 20 years.

6. Quantifying biomass needs for food, feed and fuel per capita

Since it is not possible to compare kilograms of rice, liters of milk, kWhs of electricity and liters of gasoline, for our study all biomass demands should be converted into one common unit. We use 1 kg of cereal as unit. Cereals (wheat, rice, corn) supply 70% of the calories consumed in the world and are major resource for livestock feed [8,9]. Further cereals are also an important feedstock for the present first generation transport fuels [18].

Consumption patterns differ a lot, in developing countries they mainly consists out of staple food (grains, beans etc. [19].). Such a consumption pattern requires 400 kg of cereal per person per year. With increasing economic development the consumption patterns become more luxurious and start to include meat [14]. In the developed countries 100 kg of meat per person per year is consumed [8]. It requires 4 kg of wheat for the production of 1 kg of meat [20]. This implies that affluent diets require an additional 400 kg of cereals as livestock feed. For our simple model calculation, the total need for food and feed for affluent diets is therefore 800 kg per person.

To assess the amount of biomass needed for energy production we calculate the amount of grains needed to produce a certain amount of an energy carrier. There are different routes to convert biomass into energy: it can be combusted in power plants yielding electricity, grains can be fermented providing ethanol that can be used as a transport fuel, but biomass can also be used in a digester, producing methane (gas). Using biomass as a feedstock for electricity generation provides the largest CO_2 savings; in that case biomass is replacing gas, or coal [21]. The heating value of dry biomass is 18 MJ/kg. This factor can be used to convert energy, expressed in Joule, into biomass needs (grains). For our example, the production of 20 GJ of energy requires about 1100 kg of

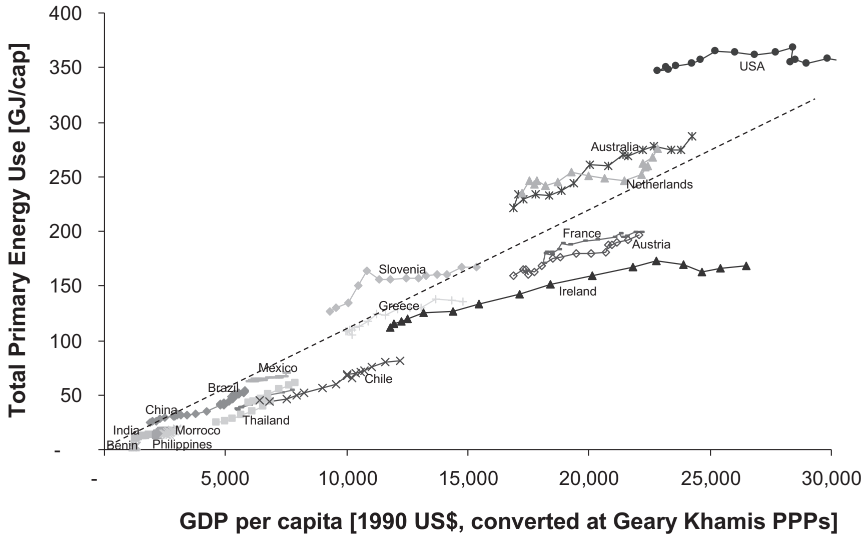

Fig. 7. Energy use per capita as function of GDP. Dotted line shows relation used in this paper. (Data are for the years 1990–2005; sources GGCD, [12]; EIA, [17]).

biomass. It is essential to realize that if we would focus on grains required to produce 20 GJ of ethanol this would require 3 times as much biomass (over 3000 kg), this has to do with the low efficiency of the conversion process (35% [22],). Second generation fuels do not compete with food as they use other biomass sources, but their efficiency is in the same order of magnitude as for the production of 1st generation biofuels [22]. So the production of 20 GJ second generation transport fuel still requires over 3000 kg of biomass.

7. Comparison of biomass needs for food, feed and fuel on a global scale

We now use this basic categorization and assumptions to assess changes in global biomass needs in the near future. Fig. 8 shows the results per person (kg/capita) for the present and for the near future. The 1 billion people in the developed part of the world require 400 kg cereals for food and 400 kg for feed. The other 5 billion people (3 billion in developing countries and 2 billion in the transition countries) have very simple menus, containing only very small amounts of affluent products. They require only 400 kg of cereals per person. Assuming changes in biomass demand as discussed in the Sections 5 and 6, the following picture emerges: consumption patterns in the developing countries remain at the same basic levels; therefore still 400 kg of cereals are needed per person. In transition countries higher shares of animal products enter the diet, implying an additional need for livestock feed of 400 kg per capita. In developed countries, menus do not change, but biomass is needed as a result of changes in the energy supply system. When 10% of the energy requirements have to be fulfilled with biofuels an additional 1100 kg of biomass is needed. As a consequence, in these countries the need for biomass for fuel is considerably larger than the combined need for food and feed. In the present situation a person in the developed world requires twice as much cereals as a person in Africa, while in the near future this difference becomes even larger, a person in the EU/USA requires four times as much.

At the global scale, the present need for cereals is about 2800 MT per year (Fig. 9). The largest share, 2400 MT, is for food, 400 MT is needed for livestock feed, for meat consumption in the developed countries. The total need for food is largest in developing countries (1200 MT) due to the number of people living there. The total cereal demand in transition countries (2 billion people) is as large as the demand in developed countries (1 billion people).

At the global scale, the large population increase in the less developed countries leads to an additional need for food of 800 MT, while the cereal needs for food in the other parts of the world remain

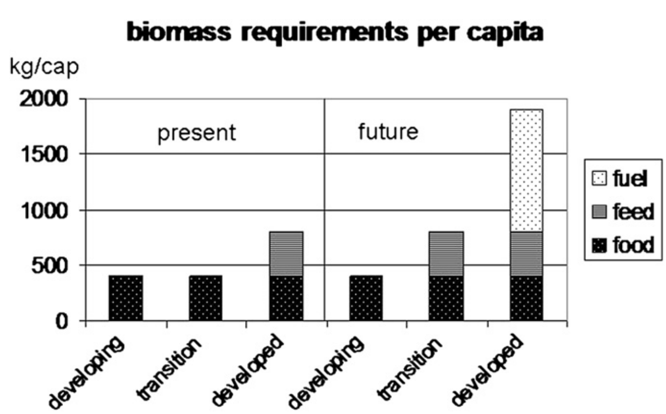

Fig. 8. The present and near future demands for food, feed and fuel per capita as calculated with the model presented in this paper.

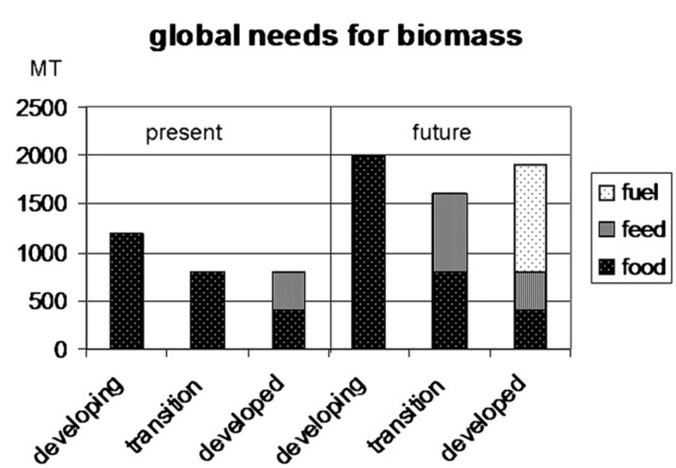

Fig. 9. Present and near future needs for food, feed and fuel on global scale.

the same. The need for livestock feed in the transition countries leads to a cereal demand of 800 MT, equaling the additional need for food in developing countries. Finally a large cereal demand as energy carrier (1100 MT) in developed countries emerges.

The overall result of this basic model calculation is that within 20 years the global demand for cereals will almost double from 2800 to 5500 MT.

8. Comparing outcomes with results other studies

The model presented in this paper involves large simplifications. It only considers two different diets and one type of renewable energy in three different economies. The actual situation shows much more variation around the globe and for forecasting future needs for food, feeds and fuel more detailed models will be required. The goal of this analysis, though, is to determine the order of magnitude of the need for biomass as an energy source within the next decades in comparison with the needs for food and livestock feed. Therefore we only discuss the results of the model according to their order of magnitude.

The present need for food and feed at a global scale is calculated to be 2800 MT cereals per year (Fig. 9). As indicated earlier the present global production of cereals is 2100 MT, which is lower than the model output. However, the model assumes that all needs are fulfilled with cereals, while in practice cereals only supply 70% of the calories consumed on global scale (the remainder is fulfilled with potatoes, beans etc. [8].). Moreover it is assumed that meat is obtained from livestock fed with cereals, while in practice a large share of the animal products originates from ruminants fed with roughage. Correcting for this, the model outcomes reflect the actual situation quite well.

With respect to the future needs the model outcomes show an increase of cereal demand by 1600 MT (50%) for food and feed within 20 years; this is in accordance with FAO estimates [2]. The OECD-FAO report [3] on biofuels and food claims that half of the extra needs for cereals in the near future will be due to the use of biomass for energy purposes. In our model this value is 30%; this difference can be again explained by the fact that we assume that all food is provided by cereals, and therefore the fraction needed for energy purposes will be smaller.

With respect to the need for food, feed and fuel within the next decades, the results of this basic model show the same pattern as those provided by more complex models used by FAO and OECD [2,3]. This implies that the values presented are in accordance with the estimates available in this research field. We can now focus on the consequences of our findings for the food supply system.

First it is striking that the need for biomass for energy is huge in comparison with the need for food and feed. The policy goal of obtaining only 10% of the energy needs from biomass is going to more than double the biomass needs in developed countries. Presently 400 kg is needed for food, 400 kg is needed for livestock feed, and the need for energy will be at 1100 kg per person per year (Fig. 7). According to these values, the need for energy will be nearly three times as large as the need for livestock feed.

This 1100 kg of cereals for energy is result of the assumption that all biomass is converted to cereals and that this biomass is used for electricity generation. In practice we don't need cereals for combustion, all types of biomass will do. The use of residues from agriculture is frequently mentioned as energy source [23]. The analysis above makes assessment of these residues possible: In the developed world at least 1100 kg biomass needed, the present system supplies 800 kg wheat. When growing wheat also straw is produced (1.0 kg of straw per kg of wheat). So 800 kg of wheat comes together with 800 kg of straw. The residues from the food system are not enough to fulfill the bio-energy needs and extension from the production remains necessary. In all these calculations the biomass is converted into electricity, the main practice at the moment is converting cereals into transport fuel. As mentioned earlier in this paper the production of 20 GJ transport fuel requires 3000 kg of biomass. If this conversion route is used the needs for biomass for energy will be far larger than calculated here.

It can be concluded that a person in the developed world, with a luxurious diet and obtaining 10% of his/her energy from biomass requires four times more biomass resources as a person in a developing country on a simple diet and without access to comparable energy sources. The value is still more than twice the amount of biomass per person used in the transition countries. This large difference results from the high-energy use levels in the developed part of the world: Fig. 5 shows that they are above 200 GJ per person per year. The average food consumption per person equals only about 10 MJ per day (2500 kcal): on annual basis this is 3.6 GJ. When 10% of the total energy demand is to be fulfilled with biomass, 20 GJ is needed: this is five times the need for food.

9. Consequences of findings for global cereal markets and food security

The present production of Asia and Africa is 1250 MT and they import 100 MT from the global market (Fig. 1). In the coming decades their needs for food increase with 50% from the present 1350 MT to 2050 MT in 2030, due to increase of population and changing consumption patterns. In the last 20 years production in Africa increased with over 70%, in Asia the increase was smaller: 40% [8]. Based on the achievements in history the increase in production of 50% in the coming decades seems possible.

Another picture emerges when we study Europe and the US. Presently they are net exporters they produce more cereals (1050 MT) than they can consume (950 MT) and export 100 MT. Their production has to double in 20 years to meet the needs for energy (1100 MT). However, in the last 20 years the cereal production in these continents increased with only 10% [8], so in these continents major system changes are needed to meet the increased requirements. Climate policy plans recognize this problem and mention that extra imports are needed to achieve the biomass for energy goals. This may mean that OECD countries change from net exporters into net importers.

However, presently the exports from both EU as USA play vital roles in food security in many low-income countries. 75–80% of grains available on the world market is imported by developing countries and used for food and feed. The situation in Africa is worst: this continent is actually importing 30% of its demand for wheat and maize. For individual countries even larger values are found: Egypt is importing 50% of its demand [3]. When the EU and USA reduce their exports this may lead to shortages on global markets, increasing costs for food and food security problems in third world countries. Moreover the need for biomass for fuel in the OECD countries (1100 MT) is 4 times larger than the total volume available on the world markets (285 MT). When present energy plans are really put into practice by implementing regulations and incentives, the cereal demand will be far larger than is available at present. Resulting in serious disturbances on global food markets. This implies that the present energy policies in the OECD countries carry the risk of generating food insecurity in low-income countries.

The analysis conducted above shows that use of biofuels is likely to affect global food security, it is in contrast with papers showing a large potential for this energy source. It is interesting to evaluate how such different conclusions can be drawn by studying the same system. Assumptions made with respect to need for food, feed and fuel do not deviate from assumption made in the positive studies

[5,24]. The major difference is that we differentiate between various economies with respect to their needs and production possibilities and that we take the present situation on the global market as starting point. When we apply our results in the global average picture a very positive biofuel future emerges. The present total global food production involves 2800 Mton wheat (Fig. 9). The residues from this system involve 2800 Mton straw. The future needs for biofuel involve only half of it: 1100 MTon. Based on this calculation the present residues from agriculture are enough to fulfill our needs for biofuels. This is in accordance with calculations by [23]. So potentially the globe is able to produce enough biomass for energy supply, however in practice this means that all biomass in the world should be collected and shipped to the US/EU. The capacity of the present global food transport system is 900 MT per year (total global food exports [6,7],), the needs for biomass for fuel imply at least 1100 MT. So the capacity of the global transport system (harbors, railways, roads) has to double within the next decades to facilitate the needs for 10% energy from biomass in the OECD countries. Such a huge system change is rather unlikely.

So the globe is able to supply the needs, but mankind is not able distribute this production. This means that importing large amounts of biomass or biofuels will not be possible and that incentives to increase biofuel use are likely to affect local and global food markets.

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