BMK Bachelor Thesis

Food vs. Fuel

Biofuels for sustainable development?

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Foreword

As an Environmental Sciences student I am always aware of articles in the newspapers that are dealing with environmental issues, therefore the topic chosen for this BSc thesis is not very hard to explain.

One look at the newspapers from the beginning of 2008 is enough to see that there is a very lively discussion going on on the biofuel vs. food topic. There are many different views and opinions on the question if biofuels are a sustainable solution for the world's energy problems and the discussion is held at many different levels. Personally I find this question very interesting and I decided that it would be a good topic for my bachelor thesis.

For my bachelor program I did several courses in the Environmental Economics and Natural Resources group at Wageningen University. When it became clear to me that it was possible to write my thesis at this group I soon decided that this was probably the most suitable group for my subject. In a first meeting with prof. dr E.C. van Ierland it was decided that I could write my thesis on the biofuel vs. food debate at the ENR group and that he would do the supervising himself. I want to take this opportunity to thank him for doing this.

In this bachelor thesis I will try to give an insight in the biofuel vs. food debate on the basis of statistical data and literature research. I also developed a model that shows the land requirements for food production and biofuel production. Since this is a BSc thesis some assumptions were made due to time constraints. When reading this research one has to keep in mind that the accuracy therefore can be questioned and the results should not be taken for granted. In further studies an improvement of the data and more realistic results can be obtained.

1. Introduction

1.1. Introduction to the problem

The production and consumption of biofuels is growing at a very high rate. As can be seen from figure 1 the global bio ethanol production almost doubled in a period of only 5 years and the production of biodiesel increased even more (FAO, 2007a).

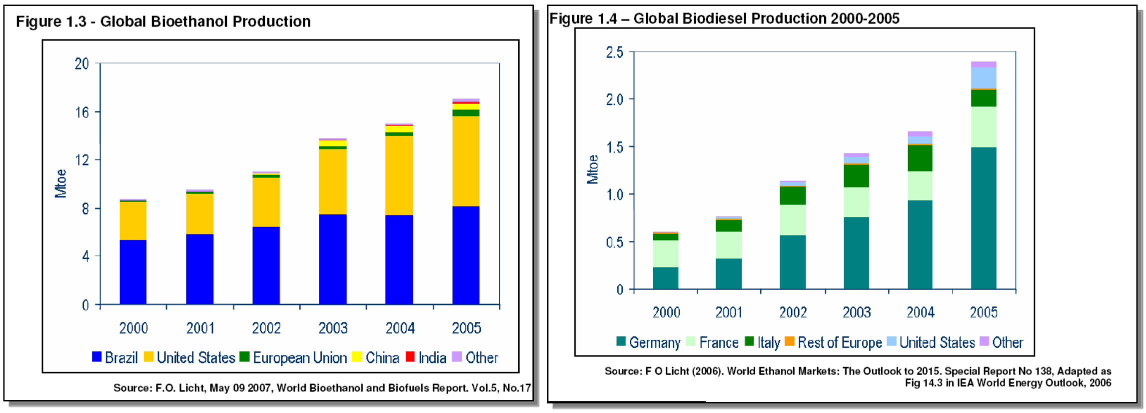

Figure 1 Global Bioethanol and biodiesel production. (Source: FAO 2007a)

The reasons for the increased use of biofuels differ amongst different areas in the world, however some main driving forces are (FAO, 2007a):

- **The rising oil prices and an increased focus on energy security:** The oil prices are rising because of increased consumption and decreasing fossil fuel stocks. Therefore it becomes more and more profitable to use biofuels over fossil fuels. Also the mayor oil reserves are most of the time located in unstable countries, this can make energy supply very uncertain and put your economy in a vulnerable position. (IFPRI, 2007) (Ruth, 2008)
- **Biofuels can help to reduce Green House Gas (GHG) emissions that contribute to climate change:** the combustion of fossil have a very high net GHG emission to the atmosphere and are the mayor cause for climate change. Biofuels, if produced and used in the right way, have a potential for reducing the net GHG emissions because the crops take CO_2 from the atmosphere. (FAO, 2007a)
- **Biofuels can play a role in rural development; it creates employment and provides energy access to remote communities:** for biofuel production a large production system and infrastructure is needed, this creates employment and gives (financial) incentives for the development of rural areas. (FAO, 2007a)

Furthermore many countries are investing in using more biofuels to meet their commitment to reduce the emissions of GHGs. For example, the EU has set the target of 5.75% alternative fuel use for transportation in 2010 and 10% by 2020. (Refuel, 2008b) Countries that want more use of biofuels often try to boost the use by subsidizing them. The US government for example gives tax credits of 0.51 dollar for a gallon of ethanol and Germany lowered the taxes on biodiesel compared to normal diesel. (Ruth, 2008)

Nowadays most biofuels are so-called ‘first generation’ biofuels. They are produced from crops like maize, sugar cane and oil producing plants such as rape, coconut or soy beans. By fermenting the maize or sugar cane ethanol is made and the oily seeds from the oil plants can be used for the production of biodiesel. These can without many adjustments be used in existing infrastructures mixed with fossil fuels.

A new development is the ‘second generation’ biofuels or ‘advanced’ biofuels. These fuels are derived from lignocellulosic materials using advanced processes such as enzymatic conversion and fermentation. (FAO, 2007a) In this process agricultural residue, woody crops and grasses are converted into fuels that can be used for transport purposes. The use of woody materials and agricultural residues are a great advantage over conventional biofuels since there is no need to use edible crops as a raw material. (IFPRI, 2007)

However, the techniques to produce ‘second generation’ biofuels are not fully developed nowadays. It is shown that it is possible to produce fuels for transport from lignocellulosic materials on lab scale but the techniques are not jet implemented on large scale. (FAO, 2007a) Therefore most biofuels nowadays are ‘first generation’ biofuels produced from food crops such as sugar cane and maize.

1.2. Problem Definition

When reading different non-scientific articles in Dutch newspapers it becomes clear that a lot of uncertainty exists in the biofuel case. In Dutch and European policy biofuels are now a ‘hot topic’ and a lot of discussion is ongoing on the use of biofuels. Some articles and politicians claim that biofuels are a good solution to solve the energy and environmental problems (Volkskrant, 2008a,b,d) (NRC, 2008a,b); others are more critical and foresee all kinds of problems if the use of biofuel increases. (Volkskrant, 2008c) (NRC,2008c) (Parool, 2008) These statements are most of the time based on data and assumptions from several sources which also show large variations, this causes even more reason for discussion.

One thing that is clear however is that the increased demand for biofuels will raise the demand for raw agricultural materials and automatically increases the pressures connected with this production, in particular land use. In scientific literature and publications several concerns about the sustainability of this increased production can be found, they can be ordered in three categories; environmental sustainability, climate change and social sustainability. (FAO, 2007a).

Environmental

The impacts of biofuel crop growing differ according to the different sorts of crops that are grown, the intensity of it and the place where it is done. However, some general concerns can be found in literature.

One of the largest treads of biofuel crop growing is the conversion of natural area in agricultural land, the cutting down of forest for agricultural use leads to irreversible loss of species and their habitat. Furthermore can the heavy use of chemical fertilizers and pesticides cause acidification and toxiphication of ground and surface waters. In areas with periods of heavy rainfall also soil erosion can occur that causes a loss of nutrients and organic matter as well as eutrophication. In other words, biofuels are not automatically green. (FAO, 2007a)

Climate Change

Biofuels have a large potential for reducing the GHG emissions of fossil fuels. If the crops are grown sustainably the ideal situation is that the GHG emitted by using the fuels are compensated by growing new crops and the net emissions should therefore be zero. However, not all current biofuels offer an advantage in GHG emissions compared with their petroleum based equivalents; this depends on the way of production. The use of fertilizers can for example play a very important role.

The most important factor in the net GHG emissions is the land use. If for example a tropical rainforest is cut down to grow a bio-crop on this soil it will take decades before a net advantage in GHG emissions is realized. Furthermore if fertilizers are used the N_2O emissions increase and lead to even more GHG emissions. (FAO, 2007a)

Social

According to some estimations, nowadays already 850 million people on Earth are suffering from hunger. (FAO, 2007a) Therefore increasing the use of food crops for biofuel production can have dramatic effects, especially in areas where people spend a very high percentage of their income on food. If the prices of food rise some people might simply not be able to buy enough food any more. Given that there is only a limited amount of arable land available on earth it can be assumed that an increased demand will also increase the prices for food products.

Furthermore, farmers in developing countries do not have formal rights over their land. If the value of land increases in areas suitable for biofuel production farmers might just be thrown of their land removing their primary source of income. (FAO, 2007a)

Going back to the non scientific articles in Dutch newspapers the world wide discussion on biofuels nowadays is mainly about the social problems related to the use of biofuels and in particular the biofuel vs. food discussion. There is a wide variation in the statements that are taken by the different articles. Some say there is so much food that biofuel production will not endanger the food security (Volkskrant, 2008b) and others say that it does (NRC, 2008c). Before a decision is taken on how to formulate policy on biofuels it is important that an answer for this problem is found. Therefore this research will mainly focus on the biofuel vs. food debate.

1.3. Research Objective

This research should give an insight in the biofuel problem and should explain if the problem exists and why it exists. Furthermore it should give information of the situation related to biofuels today but also give an insight into the developments in the future.

Another objective is to build a model that shows the relation between the biofuel and food situation by combining different input data. In this way can be easily be shown how possible future development of the different factors can change or solve the problem.

Finally the research tries to find an answer to the main research question. The answer to this can be used to support decisions on how to formulate future policy on the use of biofuels. Since it is possible that a large scale production of biofuels endangers the world food security this is very important to maintain the social sustainability of our energy supply.

1.4. Research Questions

As was described before in the introduction and problem definition many countries have strong incentives to encourage the use of biofuels as an alternative energy source. It is however possible that this will endanger the world food situation. Therefore in this BSc thesis I will try to find an answer to the following main research question.

Does the large scale implementation of biofuels to overcome the energy problems pose a threat to the world food security?

In order to find a solution to this question several sub-questions arise and will have to be answered before formulating a conclusion to the main research question.

- **How much arable land is needed to produce enough food for the world population now and in the future?**
  To know if biofuel production will threaten food production it is needed to know how much food is needed and how much agricultural land this will need, now and in the future. This will a.o. be dependent on the world population and its consumption pattern. (Refuel, 2007)
- **What are the effects of an increased production of biofuels?**
  Heavy increase of the biofuel production can have negative effects as mentioned in the problem definition; these are often related to the increased land use. Therefore it is important to know how much land is needed to fulfill a certain need for biofuels.
- **How much can 'second generation' biofuels contribute to overcome the food and energy problems.**
  Second generation biofuels don't use food crops as a raw material. Therefore they can contribute to solving the energy problems without harming the food security or other problems related to the biofuel production from food crops. The question is however how much potential they have to do this.

2. Materials, Methods

Only a limited amount of land is available on earth. Therefore in this thesis it was assumed that the biofuel versus food problem is mainly about available arable land. The use of the same land for the production of biofuels will increase the demand for arable land and this potentially causes all kinds of problems as described before in the problem definition. (FAO, 2007a; Ruth, 2008). To find out whether the production of biofuels really puts considerable pressure on arable land this research first looks at the amount of land that is needed for the world food production by building a model. Later it also elaborates on the amount of biofuels needed in 2020 and the amount of land that is needed to produce them. If the amount of land needed for food and biofuel production exceeds the total arable land available problems can be expected. (FAO, 2007a) In the end, in this research I will also try to find out how 'second generation' biofuels can contribute to meeting the demands for biofuels.

The conclusion will try to give an appropriate answer to the main and sub research questions. Furthermore it will give an advice on whether it is wise to promote biofuels as the solution for future energy production and under which conditions.

2.1. Model Description

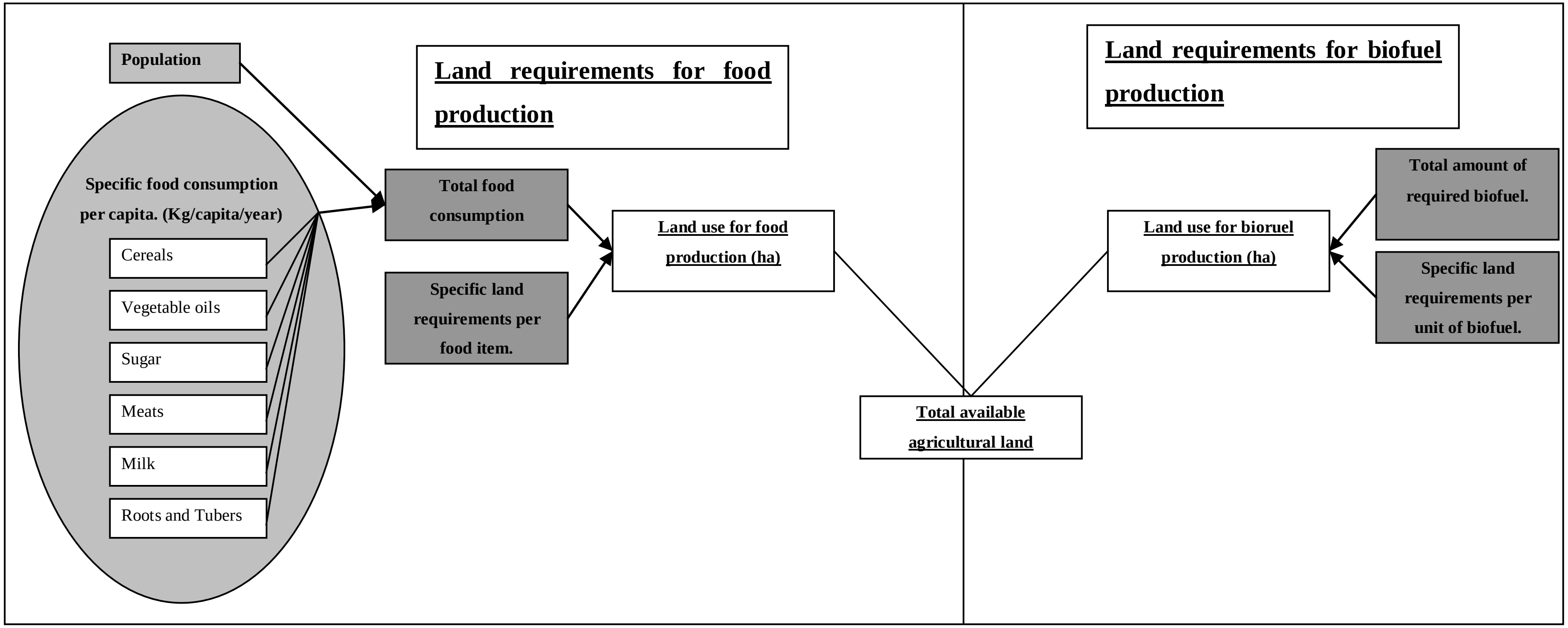

Figure 2 Land requirements for food and biofuel production

The total land requirements for food and biofuel production will be calculated by using the following formula's.

$L_f = P * Q_f * R_f$	$L_b = Q_b * R_b$
L_f=Land Requirements for food production, Ha P = Population, Cap. $Q_{f,s}$=Quantity of specific food consumed, Kg/Cap./yr $S_{f,s}$=Specific land requirements for production, Ha/Kg/yr	L_b= Land Requirements for biofuel production, Ha Q_b= Quantity of biofuel consumed, Gj R_b=Sepecific land requirements for production, Ha/Gj/Jr.

2.1.1. Model- Total land requirements for food production

The amount of arable land required for food production is mainly dependant on three factors; population size, the specific consumption pattern of the population and the specific land requirements for production per food item (see figure 2) (Refuel, 2007). These three factors will be used to give an indication for the land requirements to meet the World food consumption. Furthermore these factors can be used to make predictions for the food production according to some preset assumptions from 3 scenarios that will be explained later in this research. In this scenario's some of the factors will be variable to see the influence on land requirement:

Population

For obvious reasons the world population is an essential factor in determining the food consumption, a larger population simply consumes more. Furthermore it is also important to have more detailed data on the population of different countries since the consumption patterns in these countries differ. For example, a very large population like in China can have a very large impact on the land requirements if the consumption pattern changes, much more than in a relatively small country like the Netherlands.

Specific Food consumption per Capita

The basic food function is to provide enough energy and nutrients to maintain the body functions and physical activity. The requirements to meet this function did not change a lot since the Stone Age and is about 2200 Kcal per capita per day (Gerbens-Leenes, 2002). However, nowadays the per capita food consumption shows large differences between countries worldwide. (FAO, 2007b.) In developing countries consumption is very low and in some cases not enough to prevent hunger and malnutrition. On the other hand in developed countries, obesity is the most important cause of premature death. Figure 3 underlines this by combining the increase of energy intake with the GDP of 167 countries.

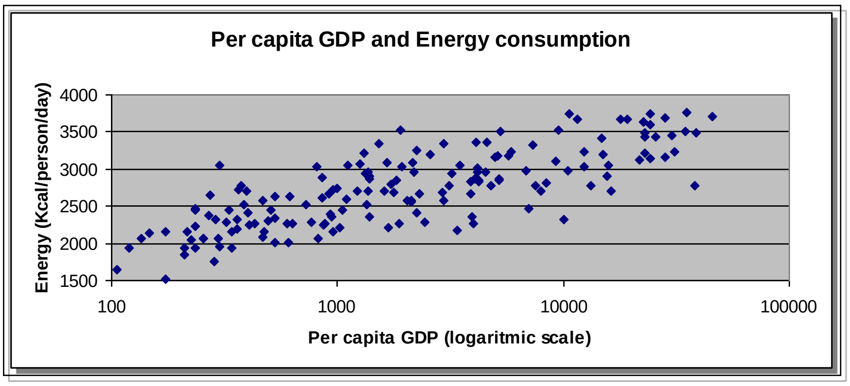

Figure 3 Per capita GDP and Energy consumption for nutrition (source data: FAO, 2007b)

Figure 3 shows that there is a clear relation between the GDP and the per capita energy consumption for nutrition. In countries with a high GDP also the energy consumption for nutrition is likely to be higher. From this can be expected that, once the GDP of a country raises, also the total energy consumption for nutrition per capita increases. This however does not necessarily have to increase the land requirements since the land required to produce a unit of food show large variations over the different food products

There are many ways to meet person's food energy requirements and all over the world large differences in the composition of diets can be discerned. (FAO, 2007b) Studies have shown that the composition of a population's diet corresponds to their income. (Zhu, 2006) In general, an increase in welfare will lead to an increase of food from animal origin. This is shown in figures 4 and 5.

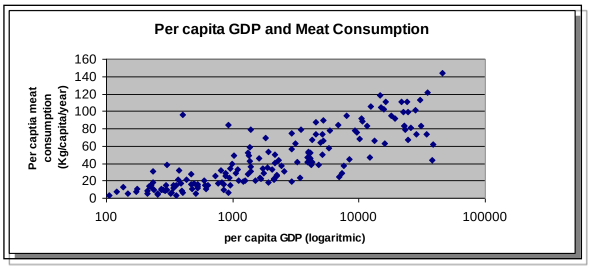

Figure 4 Per capita GDP and Meat consumption (source data: FAO, 2007b)

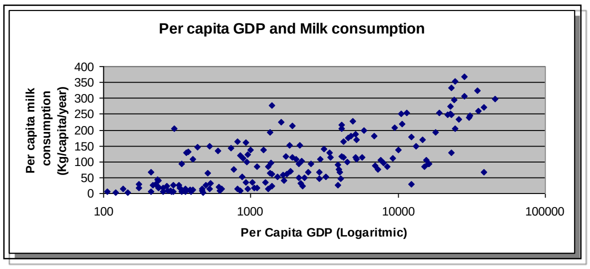

Figure 5 Per capita GDP and Milk consumption (source data: FAO, 2007b)

Specific land requirements per food item

Food production requires agricultural land. The amount of land however that is used to produce a unit of food shows large differences. Especially meats and milk require a large amount of land per Kg produced goods as can be in figure 6. Vegetable Oil, Meat and Milk products put large pressures on land requirements compared to the other food products. For the Meat and Milk this can be explained by the fact that animal products need fodders which also put pressure on agricultural land, due to low conversion efficiency of animals large amounts of fodders are needed to produce a unit of meat or milk (Gerbens-Leenes, 2002). Figure 6 shows that a small change in the composition of a diet can have large effects on the area of land required for food production.

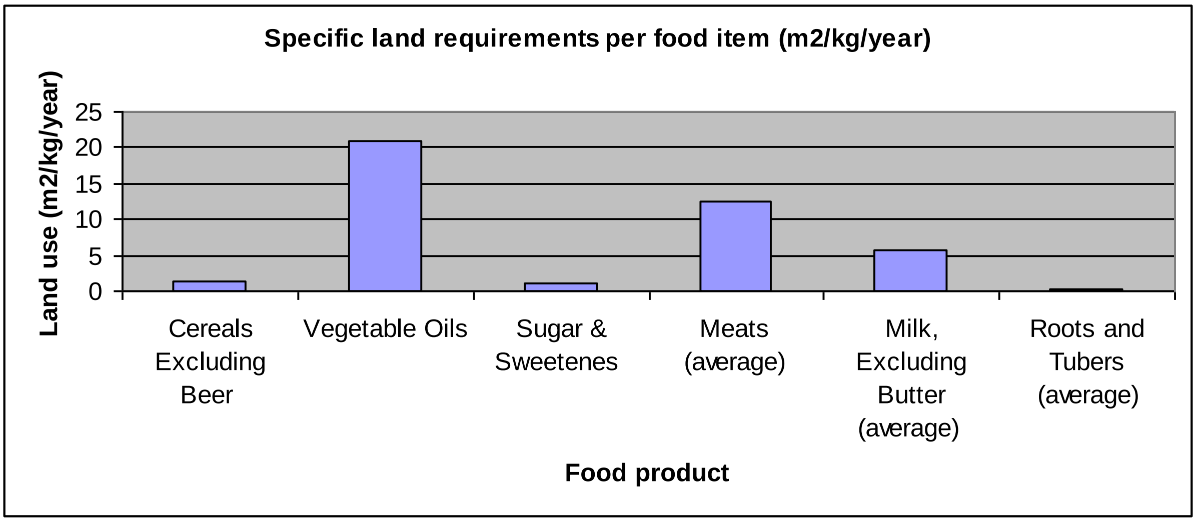

Figure 6 Specific land requirements per food item (source data: Gerbens-Leenes, 2001)

2.1.2. Model- Total land requirements for biofuel production in EU countries

Total amount of required biofuels

To get more information on the total land area that is needed for biofuel production it is important to know how much fuel is needed for transportation in 2020. The amount of biofuel that is needed depends on the aimed percentage of biofuel use. Due to time constraints in this research only the fuel requirements for Europe will be taken into account. However, the European biofuel requirements have a global impact on the land requirements since probably large quantities of raw materials and biofuels are imported from outside Europe. Europe has the aim of using 10% biofuels for transportation in 2020. Therefore this research will focus on the total biofuel requirements in Europe for 2020 based on 10% biofuel use of all transport fuels.

Specific land requirements per unit of biofuel

Depending on the sort of crop used a certain amount of land is needed to produce a unit of biofuel as can be seen in figure 7. The graph shows clearly that there is a difference in the energy yields per hectare. Although there is a variation in yield depending on the way of production and place on earth it can be seen that ethanol produced from sugar beet has a much higher energy yield per hectare, the second generation biofuels are even more efficient. In this research is assumed that for the production of first generation biofuels arable land is needed and that for second generation biofuels also other land areas such as pastures can be used. To calculate the final land requirements for biofuel production 4 scenario's were developed, each using a different type of biofuel.

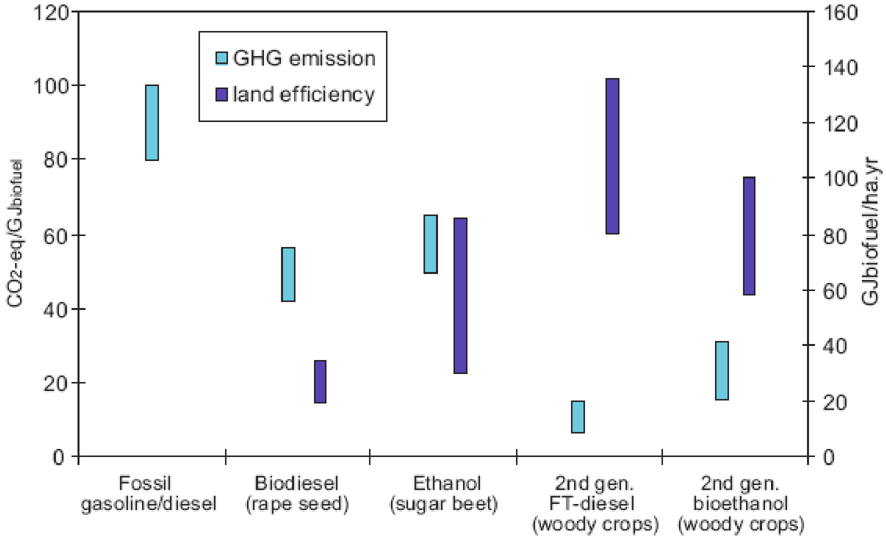

Figure 3: Greenhouse gas emissions and gross annual biofuel yields per ha[1] for the most common biofuels[2] .

[1] Average energy yields vary widely among countries and depend on climate, soils, and terrain. Energy yields here refer to an average yield across all land qualities on agricultural land and assume rain fed cultivation with sufficient nutrients and control of pests and diseases and are expressed in GJ biofuel equivalent per hectare.

[2] FT-diesel included here as representative of gasification-based biofuels. The gross biofuels yield per ha is ca 10% higher for DME, and ca 20% higher for SNG. FT-diesel, DME and SNG show comparable greenhouse gas emission reductions.

Figure 7 Annual Biofuel yields per hectare (source: Refuel, 2008b)

2.2. Food Demand Scenarios

To give an insight in the land requirements for the world food production three scenarios were developed. Scenarios 1, 2, and 3 assume a situation as it is in the year 2020. To calculate the land requirements the estimated population in 2020 is combined with the population's diet and the specific land requirements. In the scenarios an estimated annual rate of change is used to determine the population size in 2020. Since meat and milk products put the largest relative pressures (Gerbens-Leenes, 2001) on land requirements these factors will be used as variables in the model.

In the model all the countries for which data are available from the FAO database were divided into the 5 continents, Asia, Africa, Europe, North America, South America and Oceania.

Scenario 0: situation as in 2003

This scenario is based on the world population and consumption pattern in 2003.

Scenario 1: diet composition stays the same.

In this scenario the population's diet will stay the same as it is now.

The total amount of land required to meet the world food production will be calculated by combining an estimation of the population based on the current population and estimated growth rates in different parts of the world combined with the unchanged food patterns and the specific land requirements as found in literature.

Scenario 2: more meat and milk consumed by Asia

In scenario 2 it is assumed that certain parts of the world will start to consume more meat due to an expected increase in welfare. Especially countries in Asia are expected to show a substantial growth in welfare. Therefore in this scenario it is assumed that Asia will increase its consumption of meat from 28 to 65 kg/capita/year and that the consumption of milk will increase from 46 to 100 kg/capita/year. This might seem like an enormous increase but is still relatively low compared to the European and North American levels of consumption.

Now the total amount of land required will be calculated as in scenario 1. Now however the meat and milk consumption per capita in Asia is increased to 65 and 46 kg/capita/year.

Scenario 3: less meat consumed by western countries

As a final scenario a situation is assumed in which less meat is consumed in the developed countries. For a healthy food pattern the amount of meat consumed can without problems be decreased to a lower level. According to the Dutch food center (Voedingscentrum. 2008) only 100 grams of meat (or substitutes) per day is needed. On a yearly basis this means an average of about 40 kilo. In some continents however much more meat is consumed. Therefore in this scenario it is assumed that the consumption of meat is lowered with 40% for the 3 largest meat consuming continents; Europe, North America and Oceania.

The total amount of land required is calculated the same way as in scenario 1 with a 35% decrease in meat consumption for Europe, North America and Oceania.

2.3. Fuel Demand Scenarios

To calculate the land requirements for Europe’s biofuel production in 2020 4 scenario’s were used each focusing on another type of biofuel as shown in figure 7, these four biofuels were chosen because they are ‘the most common’ biofuels. (Refuel, 2008b) In the results for each biofuels is calculated how much land area is needed if only that specific biofuel was used to meet Europe’s biofuel requirements in 2020.

The biofuels used for this calculation are first generation biodiesel from rape seed, first generation bioethanol from sugar beet, second generation biodiesel from woody crops and second generation ethanol from woody crops.

3. Data

The data used for this research and especially the model was obtained from several sources. The next chapter will elaborate on which data came from which source and gives more insight in how it was used in the model.

Population, Food consumption, GDP and Land use

Data on the World population, specific food consumption, GDP and land use was taken from the FAO statistical yearbook (FAO, 2007b). This data source provides statistical information on 184 individual countries in an alphabetical order. In the database however data from 17 out of 184 countries was missing or not complete, these were removed from the database and not used in further calculations. Finally 167 countries (appendix 1) were used for analysis and grouped into continents to get a better overview of the different food patterns. One should keep in mind that the actual land requirements for food production will be slightly higher due to the missing countries.

Statistics on the population size of the individual countries originated from 2003 and was given in 1000 persons. The population sizes from the individual level were added up to the continent level and used for calculating the total food consumption per continent.

The GDP was given in $ constant 2000 prices in 2003 and was used to show the relation between rising GDP and changing food patterns.

The data on the specific food consumption per country was categorized into 5 food groups;

- Cereals excluding beer
- Vegetable oils
- Sugar and sweeteners
- Meats
- Roots and Tubers
- Milk excluding butter

Al the data is given in 1000 tons per year per country and is an average from the year 2001 to 2003. The amounts were calculated by the FAO from data on production, import, export and other use than consumption. The specific food amounts were in this research added up per continent and divided by the total population of that continent to get the consumption per capita per year for each continent.

The FAO report as well provides information on land use. For each country information is given on the total land area, arable land, permanent crops and pastures. This data was used to calculate the total arable land available worldwide for crop growing. Also the information of pastures areas can help to find out the potential of second generation biofuels. The land area is expressed in 1000 ha. The total amount of arable land available on Earth in 2003 is about 1,4 billion hectare.

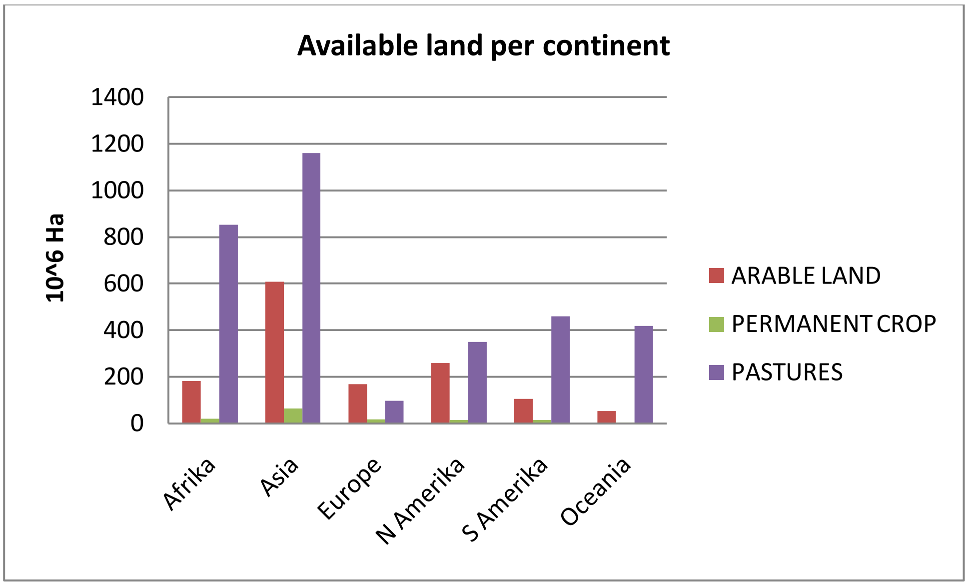

Figure 8 Available Land Per Continent (source data: FAO, 2007b)

Specific Land Requirements for Food Production

Data on the specific land requirements were obtained from an article by Gerbens-Leenes et al. (Gerbens-Leenes, 2001) on ‘a method to determine land requirements relating to food consumption patterns’. A table is shown (figure 8) that was published before in a report from the IVEM (Center for Energy and Environmental Studies) on the ‘Indirect space and energy consumption of Dutch food consumption’.

Table 1
Specific land requirements per food item (m^2 year kg^{-1})

Food item	Specific land requirement (m^2 year kg^{-1})
Beverages	
Beer	0.5
Wine	1.5
Coffee	15.8
Tea	35.2
Fats	
Vegetable oil	20.7
Margarine	21.5
Low fat spread	10.3
Meat	
Beef	20.9
Pork	8.9
Chicken filet	7.3
Milk products and eggs	
Whole milk	1.2
Semi-skimmed milk	0.9
Butter	13.8
Cheese	10.2
Eggs	3.5
Cereals, sugar, potatoes, vegetables and fruits	
Cereals	1.4
Sugar	1.2
Potatoes	0.2
Vegetables (average)	0.3
Fruits (average)	0.5

Figure 9 Specific land requirements per food item (source: Gerbens-Leenes, 2001)

Figure 8 shows the Specific land requirements in m^2/year/kg for several food items. To make these data compatible with the data on consumption patterns from the FAO database some data were averaged. Figure 9 explains how the land requirements were calculated.

Food Group	**Land requirement (m^2/year/kg)**	**Explanation**
Cereals excluding beer	1,4	Cereals
Vegetable oils	20,9	Vegetable Oil
Sugar and sweeteners	1,2	Sugar
Meats	12,3	(Beef + Pork + Chicken filet) / 3
Roots and Tubers	0,3	(Potatoes + Vegetables + Fruits) / 3
Milk excluding butter	8,4	(Milk + Butter) / 2

Figure 10 Calculation of land requirements

These data give an indication of the land requirements. However the data in the table from Gerbens-Leenes et al. is based on 'local yields and the Dutch production situation in 1990' and is possible highly inaccurate for doing predictions on a global level. The level of production in the Netherlands is of a high standard and in other parts of the world the land requirements per kg of produced good might be much higher. Since data on production in other parts of the world was hard to find data from

Gerbens-Leenes et al. was used as assumed data to be able to show the impact of a change in food consumption. However, the reader has to note that it has effect on the accuracy of the research and its conclusions.

Population Growth

The development of the population until 2020 was calculated using an estimated annual rate of change from the 'World Population to 2300' publication from the United Nations Department of Economic and Social Affairs (United Nations, 2004). In this publication the growth rate for each continent is given for the years 2000 to 2050 and is used in this research to estimate the world population in 2020. The growth rates from figure 10 were used in this model:

Continent	**Average annual growth rate (per cent) 2000-2050**
Asia	0,700
Africa	1,636
Europe	-0.283
North America	0.698
South America	0,778
Oceania	0,778

Figure 11 Annual population growth rates per continent (source: United Nations, 2004)

Biofuel consumption

The data on Europe's fuel consumption in 2020 was obtained from a publication from the European commission on the European energy and transport trends to 2030. (European Commission, 2008) This report provides predictions for the fuel consumption by transport for the year 2020 for the EU-27 countries. The data is given in Kiloton oil equivalents per year for different transport sectors. In this research only the data on public road transport, private cars and motorcycles and trucks was used since these groups use the largest amount of fuel. The Kiloton oil equivalents were recalculated to GJ. The oil consumption used in this research is shown in figure 11.

Total Fuel requirements EU-27 2020		
Transport sector	Fuel requirements 2020 (Ktoe)	Fuel requirements (1000 Gj)
Public road transport	4335	182070
Private cars and motorcycles	193342	8120364
Trucks	151841	6377322
Total	349518	14679756
Total biofuel required 2020 (10% EU aim)	34952	**1467976**

Figure 12 Fuel and biofuel requirements EU-27 2020 (data source: European Commission, 2008)

Specific Land Requirements for Biofuel production

The data for the specific land requirements for biofuel production that are used are coming from a Refuel report on biofuels for Europe. (Refuel, 2008b) In this report a graph (figure 7) is shown with a range of productivity for the 4 most common biofuels. For this research the highest value and lowest value were derived visually and an average was taken. The values used in this research are shown in figure 12.

Annual biofuel yields per ha Gj biofuel/ha/year			
	high	low	Average
Biodiesel (rape seed)	35	20	27,5
Ethanol (sugar beet)	85	30	57,5
2nd gen. FT-diesel (woody crops)	137	80	108,5
2nd gen. Bioethanol (woody crops)	100	58	79

Figure 13 Annual biofuel yields per ha (data source: Refuel, 2008b)

4. Results and Discussion

4.1. Total Land Requirements for Food Production

When all the data is combined in the model the required area land will be found for the 4 scenarios. The results of this are displayed in figure 13.

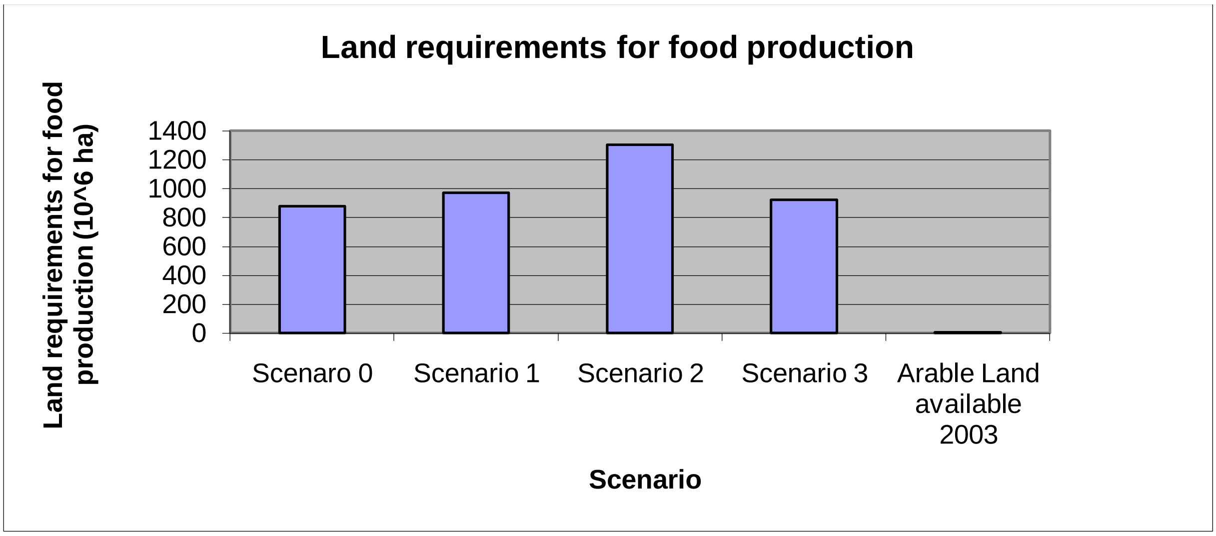

Figure 14 Land requirements for food production

Figure 13 indicates that nowadays the land requirements for food consumption already put a lot of pressure on the total arable land. In the scenario 0 the required area of land is already more than two thirds of the total arable land available.

Figure 13 also shows that the future demand of food will require large areas of extra arable land under the current efficiency of production. Scenario 1 shows that population growth will increase the demand for arable land unless the consumption pattern is changed. Scenario 3 shows that a change of diet can decrease the land requirements. In scenario 3 the increase in land requirements from population growth are compensated by a change in diet.

Scenario 2 shows that an increase of meat and milk consumption in Asia will have dramatic effects on the land requirements. If this scenario becomes reality in 2020 the land requirements will almost double compared to the land requirements in 2003. In this case more and more nature areas or grassland areas will have to be converted into arable land with all possible effects as described in the problem definition.

However, the outcomes of this model have particular characteristics, based on the assumptions made. First the data that was used on the specific land requirements were based on the Dutch productivity situation. Since the productivity in the Netherlands is probably very high this data can in fact not be used to do predictions on a global scale. If this is the case the actual land requirements will be much higher because of lower productivity in developing countries. To make the outcomes of this model more accurate more detailed data on worldwide food production is needed. This is a recommendation for further research and goes beyond the scope of this BSc thesis.

The formulation of the food scenarios were taken based upon assumptions as explained in the model description. It is however not clear if it is realistic to say that for example a doubling of meat and milk consumption in Asia can be expected. The same goes for scenario 3 where the meat consumption is lowered with 30%. In practice this could mean a diet in which 2 out of 7 days no meat is consumed. Further study could prove if these assumptions on the changes in the diet are realistic.

Finally there is also the possibility of technological development. If the productivity of land requirements for food production improve than less land is needed to produce the required food. This can for example be achieved with GMO crops or improved fertilizing or irrigation techniques. A research on possible future improvements of agriculture could give more insight in this.

4.2. Total Land Requirements for Biofuel Production

The data on total biofuel energy requirements and specific land requirements combined result in 4 land requirements, one for each type of biofuel. The results are shown in figure 14.

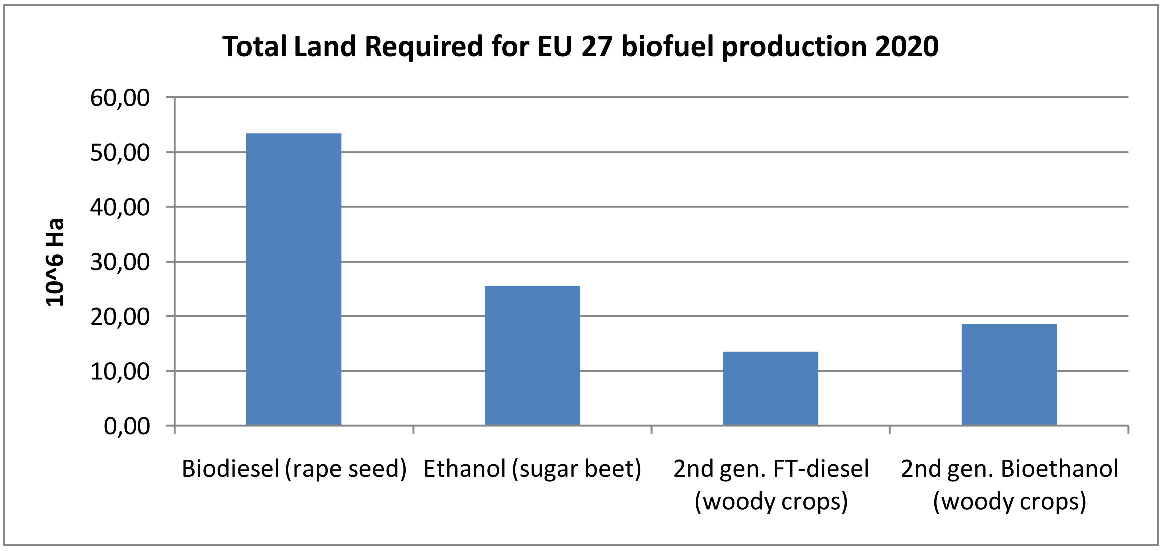

Figure 15 Total Land Required for EU 27 biofuel production 2020

This figure shows that the land requirements to meet the EU-27 countries biofuel need in 2020 show large differences. The largest land area is needed if only biodiesel from rape seed is used. If ethanol is used the land requirements are much lower. Since they are first generation biofuels the land required for this production is arable land and therefore will put extra pressures on the total available arable land.

Second generation biofuels are more efficient than the first generation biofuels. Furthermore these crops can possibly be grown on other land than arable land and will therefore put less pressure on arable land. Also residues from agriculture can be used to produce these biofuels which will further decrease the land requirements. However as said before these cannot be produced on a large scale yet and can therefore not contribute to their full potential in the near future. Further research can provide more information on the future contributions of these second generation biofuels.

Figure 14 shows the amount of land that is needed if only one type of biofuel is used. However it is also possible that a combination of these is used. Especially in the introduction phase of second generation biofuels this is very likely to happen. Also the biofuels used for the analysis are just a selection of the possible biofuels and crops. Many other crops are available that can be used for this purpose. This can also be a subject for further research.

Conclusion

Already in the first part of the analysis important conclusions can be found. When analyzing the land requirements for food production it becomes clear that most of the arable land on earth is needed already for food production and that in the future most likely even more land is needed. An increase in the use and production of biofuels will therefore put extra pressure on the demand for arable land. The increased demand for arable land will most likely cause problems as described in the problem definition.

Furthermore this research shows that the increasing world population will increase the demand for arable land. The specific diet composition of people however has a large influence on this demand; especially the consumption of meat and milk is an important factor since these goods require a large land area to produce. Also an increased welfare in Asia has a large potential impact due to the large population size.

To meet the European goal of 10% biofuel use for transport in 2020 with first generation biofuels at least 25 million hectares of land is needed. Compared to the total arable land on earth this is almost 1%. With this one percent only the needs of Europe are fulfilled. It is easy to imagine that the biofuel requirements on world scale will have a gigantic impact on the availability of arable land.

Second generation biofuels have a large potential for contributing to the world energy problems. First they have a higher efficiency per hectare and second they can be grown on land that cannot be used for arable purposes and even non edible residues from agriculture can be used for production. This decreases the pressures on arable land.

Finally from this research it can be concluded that the large scale implementation of biofuels to overcome the energy problems can be a real danger for the world food security. Therefore politicians should be really careful with taking decisions on the promotion of biofuels to reach certain sustainability aims. Biofuels for solving the energy problem of today? They can cause many problems for tomorrow.

5. References

- Adler, P. R., S.J. Del Grosso, and W. Parton. 2007. *Life-Cycle Assessment of Net Greenhouse-Gas Flux for Bioenergy Cropping Systems,* Ecological Society of America 17(3), pp. 675-691
- European Commission. 2008. *European energy and transport: Trends to 2030 – update 2007.* Belgium, Brussels, European Commission, Directorate General for Energy and Transport
- FAO. 2007a. *A review of the current state of bioenergy development in G8+5 countries.* Italy, Rome: United Nation's food and agricultural organization.
- FAO. 2007b. *FAO statistical yearbook 2005-2006.* FAO stat, vol. 1/2, Rome.
- Fischer, G., E. Hizsnyik, S. Prieler, H. van Velthuizen. 2007. *Assessment of biomass potentials for biofuel feedstock production in Europe: Methodology and results.* Land use Change and Agriculture Program, European Union
- Gerbens-Leenes, P.W., S. Nonhebel 2002. *Consumption patterns and their effects on land required for food* ,Ecological Economics 42, pp. 185-199
- Gerbens-Leenes, P.W., S. Nonhebel, W.P.M.F. Ivens 2001. *A method to determine land requirements relating to food consumption patterns,* Agriculture, Ecosystems and Environment 90, pp. 47-58
- IFPRI. 2007. *The World food situation. New driving forces and required action.* US, Washington D.C: International Food Policy Research Institute
- Mathews, J. A. 2008. *Towards a sustainably certifiable futures contract for biofuels*. Energy Policy 36, pp. 1577-1583
- Refuel 2007. *Assessment of biomass potentials for biofuel feedstock production in Europe: Methodology and results.* Netherlands, Utrecht: Copernicus Institute
- Refuel. 2008a. *Biomass Resources Potential and Related Costs. Assessment of the EU-27, Switzerland, Norway and Ukraine*. Netherland, Utrecht: Copernicus Institute
- Refuel. 2008b. *Eyes on the track, Mind on the horizon. From inconvenient rapeseed to clean wood: A European road map for biofuels.* Netherlands, Utrecht: Copernicus Institute
- Ruth, L. 2008. *Bio or Bust? The economic and ecological cost of biofuels.* From: EMBO reports 9(2), Publisher City
- United Nations. 2004. *World Population to 2300.* New York, United Nations Department of Economic and Social Affairs
- Voedingscentrum. 2008. *Basisvoeding: Gemiddeld aanbevolen hoeveelheden per dag.* Internet:

http://www.voedingscentrum.nl/EtenEnGezondheid/Gezond+eten/hoeveelheden+per+dag/, 8 June 2008

- Zhu, X., L Wesenbeeck and E. C. van Ierland. 2006. *Impacts of novel protein foods on sustainable production and consumption: Lifestyle change and environmental policy*. Environmental and Resource Economics 35, pp. 59-87

6. Appendix 1

Cd-rom with used database and model.