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Agricultural land availability and demand in 2020

A global analysis of drivers and demand for feedstock, and agricultural land availability

Part of the AEAT managed study for the Renewable Fuels Agency

Report

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Summary

Introduction
The UK Renewables Fuels Agency has commissioned AEAT to coordinate a study that evaluates the drivers of land use change, and reviews the future demand and supply of biofuels to 2020 and their impact upon GHG emissions. The following report is part of this study, and addresses the following issues:

- Current and anticipated future drivers and demand (to 2020) for land and feedstock for food, feed and other major uses.
- Global agricultural land availability.

Conclusions
The main conclusions are the following.
Food and feed production are the main sources of demand for agricultural land: in 2006, about 5 Gha of land was in use for croplands and pastures. Pastures have a large share in this, about 3.4 Gha, the remainder is used as arable land (1.4 Gha) or for permanent crops (0.14 Gha). Since 1990, the global forest area has been reduced (by 80 Mha), whereas arable land and the area used for permanent crops has increased (by 34 Mha in total). No less than half of the agricultural area is currently used for cereals production (674 Mha), 21% is used for oil crops (287 Mha).

Future food and feed land demand depends on many factors, but mainly on population growth, economical growth, global diet (meat consumption, in particular) and government policies, and on developments in agricultural yield and technology. It is expected that the demand for agricultural crops for food and feed will increase significantly in the next decades. This increase in demand is met to a large part by an increase of agricultural yields due to agricultural intensification and technology improvement, more efficient meat production and crop improvements. However, despite these improvements, demand growth is expected to be so high in next decades, that the agricultural land demand for food and feed is predicted to grow by 200-500 Mha until 2020. Compared to the agricultural land increase since 1990 (34 Mha), this is very high.

Currently second largest driver for land demand is the wood, pulp and paper industry. Wood is used for timber and paper production, and demand for these products are increasing strongly. It is also a large bioenergy source, as many households all over the world use waste wood from forests for heating and cooking, and demand for industrial bioenergy is expected to increase. Global forest area is about 4 Gha, about 4% of this is plantation forest. This area is increasing steadily. It is estimated that the area of forest plantations in 2020 will be somewhere between 190 and 310 Mha. However, uncertainties in these predictions are large, due to strong growth of wood consumption in emerging economies, but also due to other developments such as increasing environmental demands.

Accurate forecasts for global land use for bioenergy in 2020 are lacking, but various studies assess the future bioenergy *potential*. Ranges in results are very large, mainly due to assumptions or scenarios regarding the technological developments in agriculture and livestock management.

Current biofuels production (2006) uses about 13.8 Mha agricultural land, mainly due to biofuels production in the USA, EU, Brazil and China. Global biofuel demand and related land use may increase significantly in the next decade, as the global biofuel scenarios developed by E4Tech in this RFA study show. They result in a land use in 2020 that varies between 73 and 276 Mha, depending on:

- The global biofuel demand.
- The feedstock mix, i.e. whether or not high yield crops are used. and
- The share of 2nd generation biofuels that are produced from agricultural and wood residues (land demand is 30-40% less in scenarios with 2nd generation biofluels included, compared to otherwise similar scenarios without).
- The agricultural yield of these crops in 2020 (high yield estimates require 11-12% less land than the expected, business as usual yields, the low yield estimates require 20-26% more than business as usual[1]).

If the co products of the biofuels production from wheat, maize and oilseed are used as animal feed, this will partly compensate the land demand for biofuel crops. Land demand of the various scenarios can then reduce by 10-25%, depending on the feedstock mix used.

In these biofuel scenarios, the production (and thus area) of a number of crops needs to be increased significantly, compared to current production levels. In all scenarios, sugar cane is the main feedstock, requiring significant expansion of current production. Depending on the scenario, production of other major feedstocks such as maize, palm, soy, jatopha, wheat and rapeseed oil need to be increased significantly as well. Even though sugar cane is the largest feedstock in terms of Mton in all scenarios, its land use is relatively limited due to its high yield. Relatively large areas are required for soy and oil seed rape production, and jatropha in scenarios 3 and 4.

As the demand for land for food, feed, wood and bioenergy is expected to increase further in the next decade, agricultural land area is expected to increase further even without additional biofuels demand. This will result in land change, most likely at the expense of forest and, perhaps, pastures and meadows. The statistics on global fallow and idle land are incomplete, but availability of these types of land seem to be insufficient to accommodate the demand increase. We can thus conclude that the biofuels demand increase will require additional agricultural land, and thus will cause land use change in various regions of the world.

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1 It should be noted, that especially in scenarios 3 and 4 the uncertainties of the low yield land use estimate are quite large. This is due to the relatively large share of jatropha in the feedstock mix of these scenarios. As this crop is not yet cultivated on a large scale, there is currently no commercial yield data available, leading to large uncertainties regarding future yields.

The overall conclusion regarding land availability can be that there is sufficient land available for the production of food, feed and wood to comply with the rising demand in the coming decades. Either because of the expansion of the total agricultural land (at the expense of other types of land, such as forests) or because surplus land becomes available due to yield improvements.

However, several regional bottlenecks can be identified. Regions like North Africa an South Asia are already using more than 90% of the available land, so there is very little room for expansion. Furthermore, the availability of water for irrigation is just as uneven distributed as available agricultural land. And finally the direct and indirect effects of climate change and the regional distribution of those effects will have an impact as well.

Recommendations
There appears to be a large potential of improving agricultural and forest yield further in the future, and this will have a significant impact on the global and regional land use change that is to be expected in the future. Policies can thus reduce land use change, for example by promoting:

- Technological developments in agriculture.
- The use of crops with high yields. and
- The use of idle or marginal land.
- The use of 2nd generation biofuels made of previously unused forest or agricultural waste.

It is thus recommended to develop biofuel scenarios that are aimed at reducing land use, and then develop policies that can promote these scenarios. More insight into potential future yield developments for the most relevant crops and regions, and monitoring of the developments in this area might be required for this. Accurate monitoring of future developments in agricultural and forest land areas is also to be recommended.

Achieving yield improvements by good agricultural practices and agricultural intensification is crucial to limiting the demand for agricultural land. However, one has to weight the environmental benefits from the reduced land use against the environmental impact of agricultural intensification. The same can be said about converting idle and set aside land to agricultural use.

As there are large regional differences in land and feedstock demand and land availability, regional impacts of policies may vary significantly. We recommend to analyse these further, and take these into account when assessing the impact of biofuels policy in more detail.

The global biofuels production increase that is expected for the next decade will have a very profound effect on the market of commodities also used as food or feed. Effects on prices should be considered, and care should be taken to reducing these effects, for example by allowing agricultural markets to adjust, and agricultural production to increase sufficiently over time.

The estimate of the biofuels feedstock scenarios and land use demand in 2020 could be improved further. For example, this analysis should take into account the interaction between the food, feed and biofuels market, the impact of biofuels policy in prices and shifts between commodities, the impact of yield developments and the effects of sustainability certification.

1 Introduction

1.1 Introduction

The UK Renewables Fuels Agency has commissioned AEAT to coordinate a study that evaluates the drivers of land use change, and reviews the future demand and supply of biofuels to 2020 and their impact upon GHG emissions. The following report is part of the first study, the drivers of land use change. It addresses the following issues:

- Current and anticipated future drivers and demand (to 2020) for land and feedstock for food, feed and other major uses.
- Global agricultural land availability including idle land, including the potential role of feedstocks cultivated on poor quality soils, salt water environments and in arid areas.

1.2 Scope and key aims

This study looks at global demand for land, and land availability, with a focus on the situation in 2020. As regional differences in trends and availability can be quite significant, regional data, trends and issues will also be addressed.

The key aims of this study are to

- Assess the future trends in demand for agricultural and forest feedstocks and the resulting demand for land.
- Asses the global availability of agricultural land.

Due to the limited time available, the study focussed on global reports on land demand and use, more detailed regional studies were not included in this assessment. For the same reason, it was not possible to conduct an in depth analysis or extended literature review of the drivers and uncertainties regarding the agricultural market developments, and resulting food and feed land demand and production. The study rather aims to provide an overview of the most relevant and recent literature, and an assessment of the potential impact of the global biofuel demand increase on land use.

1.3 Key activities

This study was based on a literature analysis, and due to the limited time available, we focussed on studies with a global scope. An overview of the literature sources used in this analysis can be found in the literature list at the end of the report, and in Annexes A and B.

A draft of this report has been reviewed by André Faaij, associate professor at the Copernicus Institute for Sustainable Development of the Utrecht University. The authors would like to thank him for his comments, they were incorporated in the final report where possible[2].

Regarding expected global demand for biofuels, the results of the substudy by E4Tech were used, and yield data provided by ADAS. The effect of co products on land use demand in the various scenarios was taken from the CE Delft substudy on co products.

[2] Please note that we did not address all comments, as some relate to topics dealt with in other (sub)studies for the RFA, others could not be incorporated due to the limited time available for this study.

2 Current and future drivers and demand for land

2.1 Introduction

This chapter provides an overview of the main drivers for agricultural land and feedstock, with a focus on 2020. The impact of each of these drivers on feedstock and land demand is assessed.

Total demand for agricultural and forest land basically depends on two factors:
a Demand for agricultural and forest feedstock. and
b Land requirements of each of these feedstocks.

The first depends on many economical and societal developments, including population growth, income developments, urbanisation and other economical, technical, political and agricultural developments. Examples of the latter are improvements of production technologies, capacity building, infrastructure, etc., which may reduce the price of the various products. Land requirements of these products are directly related to the yield per hectare of the various products, which depends on the type of feedstock and crop used (i.e. on the type of food, feed, wood, biofuel, etc.), on the region and type of land where it is grown, on the environmental conditions and agricultural practice (such as agricultural and livestock management).

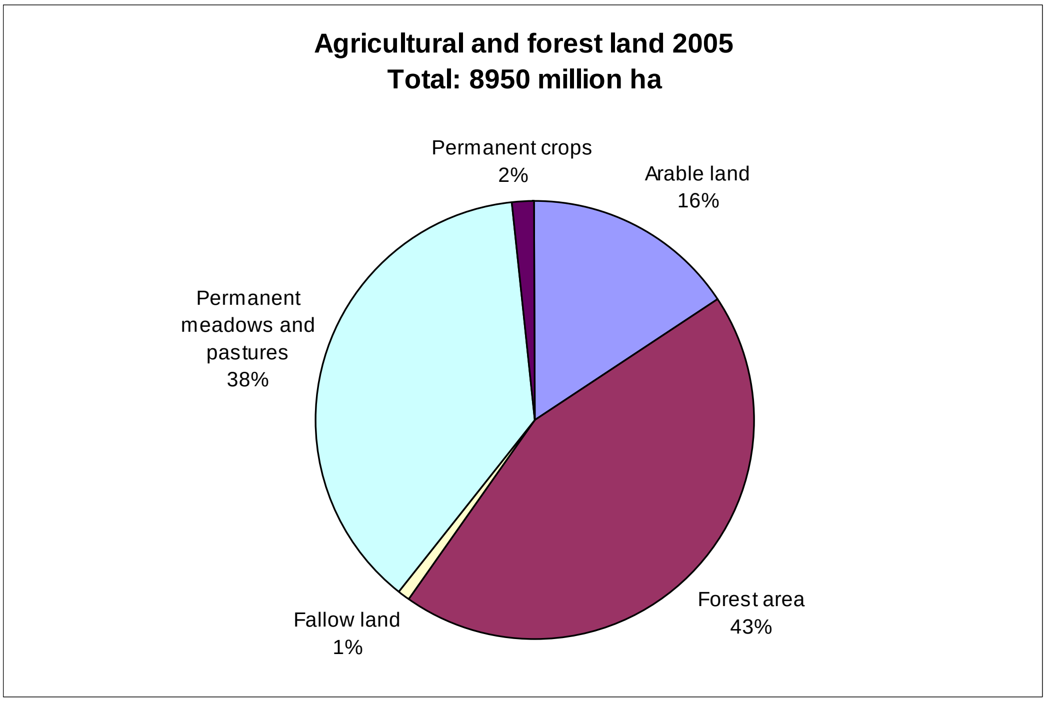
The analysis in this chapter was based on various literature sources that have assessed and modelled the current and future developments in this area. An overview of the literature used for this analysis (including information on the drivers analysed, methodologies used, and results) can be found in Annex A. A very extensive review of global studies on biodiversity, water, macro-economic analyses and energy and food demand has recently been carried out for the Dutch government, coordinated by the Copernicus Institute of Utrecht University (WAB, 2008). Their report will be published soon.

In the following chapter, first an overview is provided of the current agricultural land use for each of these drivers (based no FAO statistics). Then, forecasts for land use demand of each of these drivers will be presented and discussed .

2.2 Current land use

Globally, almost 9 billion ha are currently in use as agricultural land or forest. 43% of this (3.9 Gha) is forest area, of which about 3.5% is forest plantation. 38% (3.4 Gha) is in use as permanent meadows and pastures. The remainder, 1.6 Gha is in use as arable land (1.4 Gha) or for permanent crops (0.14 Gha). The share of fallow land is only small (and, in many countries, not registered, so that the statistics are poor on this).

Figure 1 Current land use (2005)



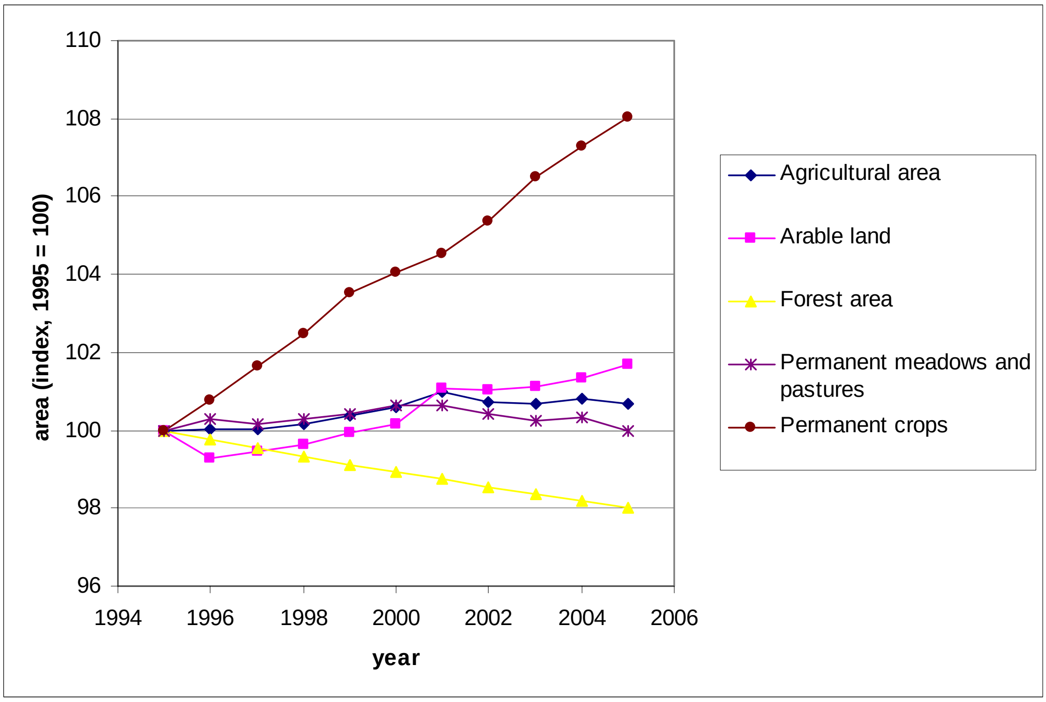
Source: FAOSTAT.

The recent trends in these land areas are shown in Figure 2. Between 1995 and 2005[3]

- Global forest area was reduced (80 Mha).
- Arable land increased (24 Mha).
- The area used for permanent crops increased (10 Mha). and
- The pastures and meadows area was fairly constant.

[3] Due to lack of data on fallow land in the FAOSTAT database, we can not draw any conclusions on the fallow land developments.

Figure 2 Land use developments between 1995 and 2005 (index, 1995 = 100)

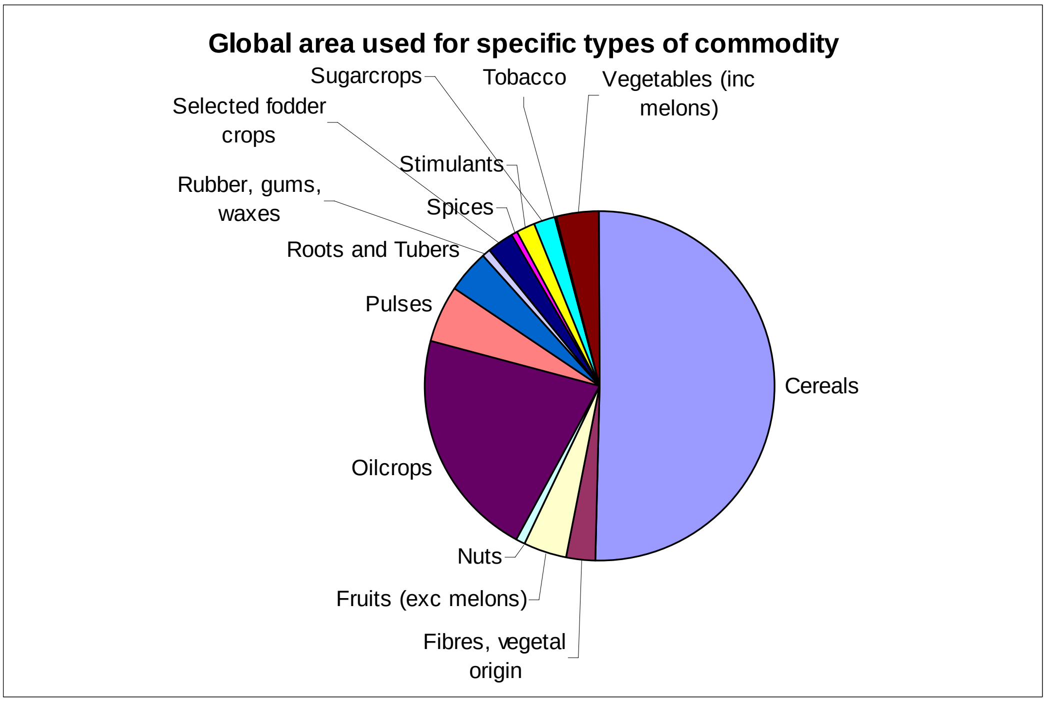


Source: FAOSTAT.

The types of crops currently grown on the arable land and permanent crops land is shown in Figure 3. No less than half of the area used for global agricultural production is used for cereals production (674 Mha), 21% is used for oil crops (287 Mha). For comparison, sugar crops only use about 2% (26 Mha). When looking at the developments in land use per commodity type since 1990 (Figure 4), we can see that the main changes in this period were the following:

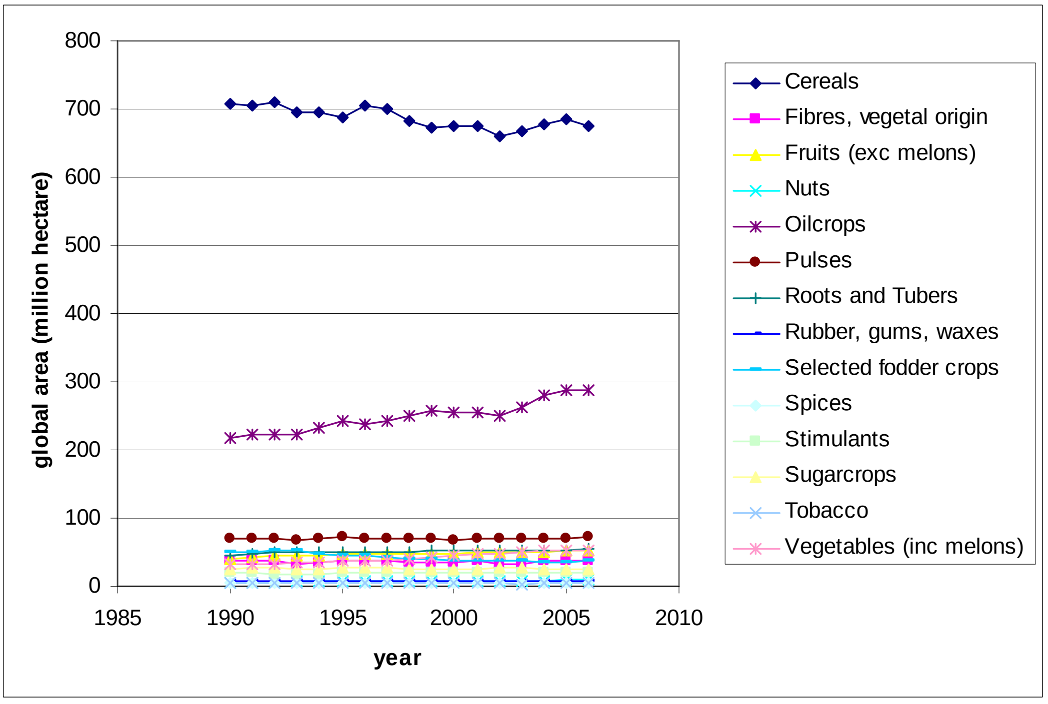
- The area used for cereal production decreased by 5% (35 Mha).
- The area used for oil crops increased by 31% (69 Mha).
- In addition, the area for vegetables and fruits production increased significantly, by 22 and 10 Mha respectively. and
- The area for selected fodder crops decreased (by 13 Mha).

Figure 3 Share of land use of various commodity types, in 2006



Source: FAOSTAT.

Figure 4 Developments in land use of various commodity types, between 1990 and 2006 (Mha)



Source: FAOSTAT.

2.3 Future land use (2020)

To estimate future demand for land, we can distinguish various drivers for land use, namely demand for

- Food and feed.
- Wood.
- Bioenergy.
- Biofuels.
- Other products.

2.3.1 Land use for food and feed

Several sources describe the development of future food demand. Table 1 presents the estimated area of land needed for crops and pastures in the literature that was considered to be most relevant for this study. Values are converted to 2020 by assuming linear trends from now till the year of study (mostly 2050).

Table 1 An overview of the results on land use for food and feed in the literature analysed

Source	Base year and land area in that year (Gha)	Year of study and land area in that year (Gha)	Land use 2020 (Gha) (linear interpolation)
Hoogwijk et al., 2003	2000 Croplands + pastures: 5.0	2050 Croplands + pastures: 1.3-5.0 (most realistic (2.5-5.0)	3.5-5.0 (most realistic: 4.0-5.0)
UNEP, 2007		2020 Croplands + pastures: 5.2-5.7	5.2-5.7
Smeets et al., 2007	2002 Croplands: 1.5	2050 Croplands: 1.3-4.2	1.4-2.5
	2002 Pastures: 3.5	2050 Pastures: 3.5-3.8	3.5-3.6
Fischer and Schrattenholzer, 2001	1990 Croplands: 1.52	2050 Croplands: 1.74	1.63
	1990 Grassland (pasture, woodlands and shrubs): 3.38	2050 Grassland (pasture, woodlands and shrubs): 3.30	3.34

As can be seen there is a huge range in the predicted values, due to different assumptions used and different scenarios that were analysed.

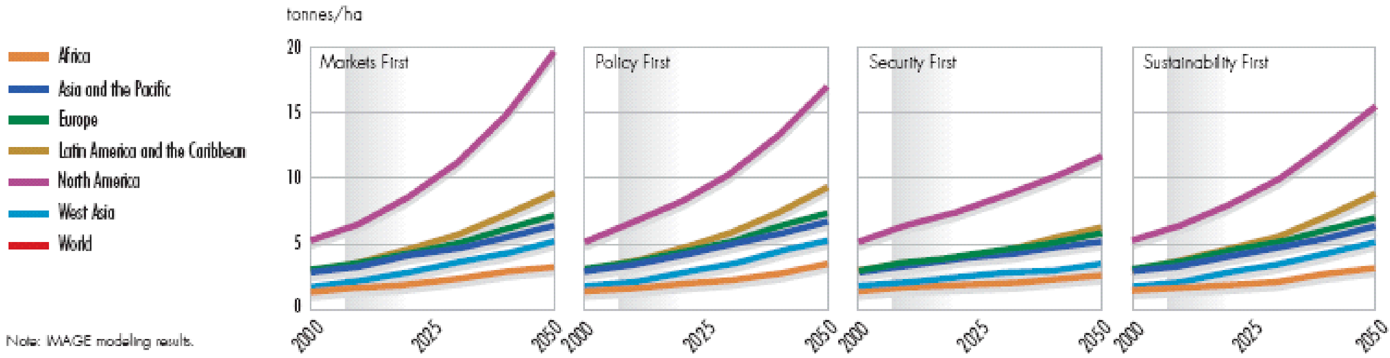
The range is especially striking in Hoogwijk et al. In that study, three food intake scenarios are assessed: a vegetarian diet with little or no animal protein, a moderate diet as well as an affluent diet with a large share of meat and dairy products. Because meat and dairy production are very inefficient (in terms of land use) and a lot of land is required for cultivation of fodder, eliminating or adding animal proteins (meat, dairy) from the diet has an enormous influence. As we do not consider the vegetarian and affluent diets to be very realistic for 2020, we discarded these results in the analysis here. The range then decreases to 2.5-5.0 Gha and is caused by three prognoses for population growth and two scenarios for technical development of the agricultural sector. Their maximum is still low compared to other studies, because they assumed that the total area for food production does not increase in the future.

In (UNEP, 2007) the range is caused by differences in political and societal choices. In this study four scenarios are constructed:

- *Markets first*: the private sector, with active government support, pursues maximum economic growth.
- *Policy first*: government, with active private and civil sector support, initiates and implements strong policies to improve the environment and human well-being, while still emphasizing economic development.
- *Security first*: government and private sector compete for control in efforts to improve, or at least maintain, human well-being for mainly the rich and powerful in society.
- *Sustainability first*: government, civil society and the private sector work collaboratively to improve the environment and human well-being, with a strong emphasis on equity.

In each scenario the world develops in a different way, which is reflected in the total demand for food as well as in the state of agricultural practice. This is illustrated in Figure 5, where the cereal yields are shown per region, as used in these four scenarios. As the graphs show, the increasing demands for food, along with greater investments in technology results in the largest increases in cereal yield in *Markets first* and *Policy first*. Cereal yields are significantly lower in *Security first*.

Figure 5 Cereal yields by region



Source: UNEP, 2007.

However, despite the relatively low yields in *Security first*, land demand for food and feed is lowest in that scenario, illustrating that other developments such as in population growth and economical growth are relevant too. This results in 5.2 Gha of cropland and pastures in *Security first* to around 5.7 Gha in *Policy first*.

In Smeets et al. (2007) levels of advancement of agricultural technology are responsible for the range in land use. Since all studies but (Hoogwijk, 2003) have not started with the assumption that the area for food production does not increase in the future (but rather calculated land demand for food and fodder), we consider these provide more accurate forecasts for land use than (Hoogwijk, 2003).

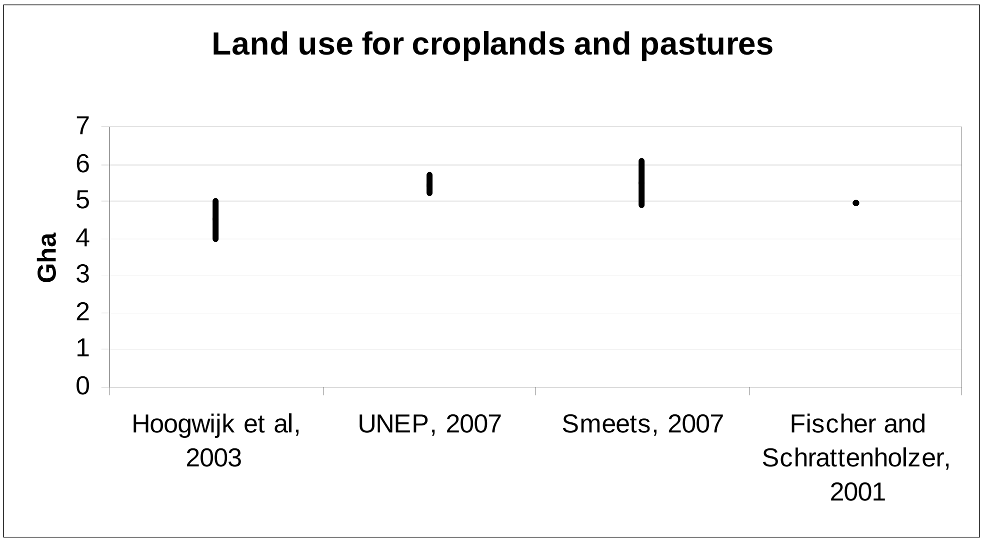
The uncertainty in predictions for land use for food and feed production is significant. This is caused mainly by uncertainties in the development of agricultural practice and uncertainties in food demand and the share of animal products in future diets[4].

More studies are available that predict future demand for food (for example OECD-FAO, 2007; MNP UNEP, 2006; Rosegrant et al., 2000), however, the demand is in these studies is not converted to land use. To calculate the land use associated with this demand, a detailed study on future regional demand and supply, and associated yields corresponding to their scenarios would be necessary. Due to a lack of time this has not been done here.

Figure 6 presents the ranges from the different studies (croplands and pastures together, since Hoogwijk (2003) does not distinguish between the two). On basis of the presented ranges, and considering the modeling methodologies used, it can be concluded that future land use for cropland and pastures will be between 3 and 6 Gha, probably around 5.5 Gha. Although demand for food and the share of meat within the diet increases, future land use for food is more or less the same as the current level. This means that increasing demand is for the largest part set off by increasing yields due to technology improvements. This conclusion is endorsed by IFPRI (1999), that predict that about 70% of the increasing production of cereals is taken care for by yield improvements. UNEP (2007) present similar results with their scenarios, they predict an increase in cereal yield from 2000 to 2050 from 20% in Africa to 300% North America.

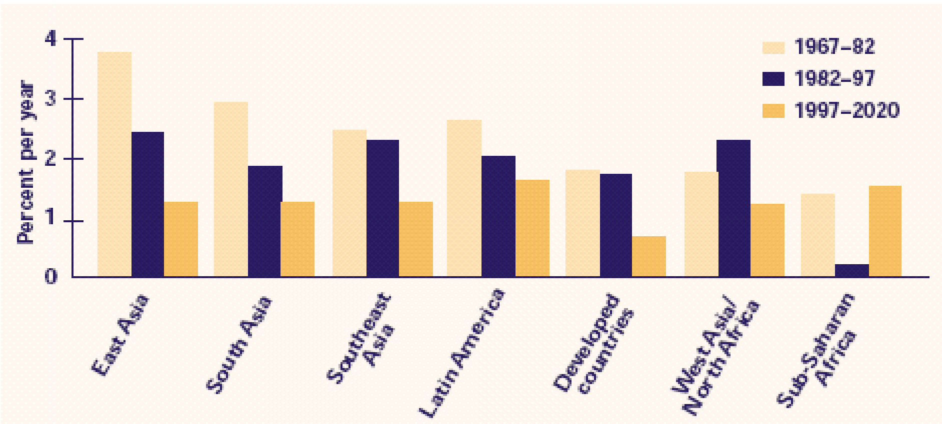
[4] Other studies aimed at determining the maximum biomass potential confirm that conclusion, as is confirmed by (Dornburg et al, 2008).

Figure 6 Global land use for croplands and pastures, in 2020



These data are for the global scale. There are however, big regional differences, both in yield developments and in demand. For example, Rosegrant et al. (2001) present the historical and future annual growth in yield per region (see Figure 7). For the period 1997 to 2020 an average annual yield improvement of around 1.2% is predicted.

Figure 7 Cereal yield growth rates per region 1967-2020

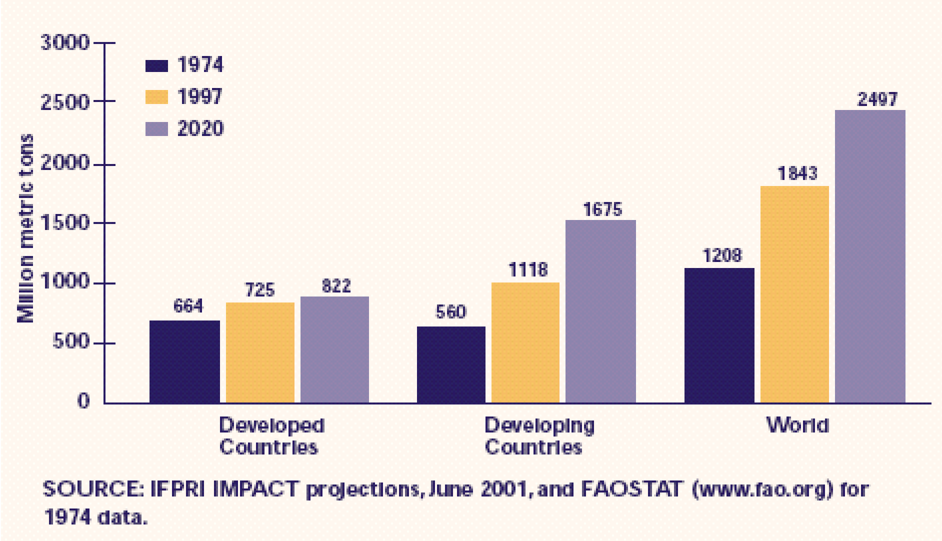


Source: Rosegrant, 2001.

Rosegrant et al. (2001) also presents separate demand data for the developed and developing world[5]. From this it can be concluded that the growing demand for food is especially huge in the developing world (see Figure 8 and Figure 9). The results predict that China and India are together responsible for 39% of the increase in global cereal demand from 1997 to 2020.

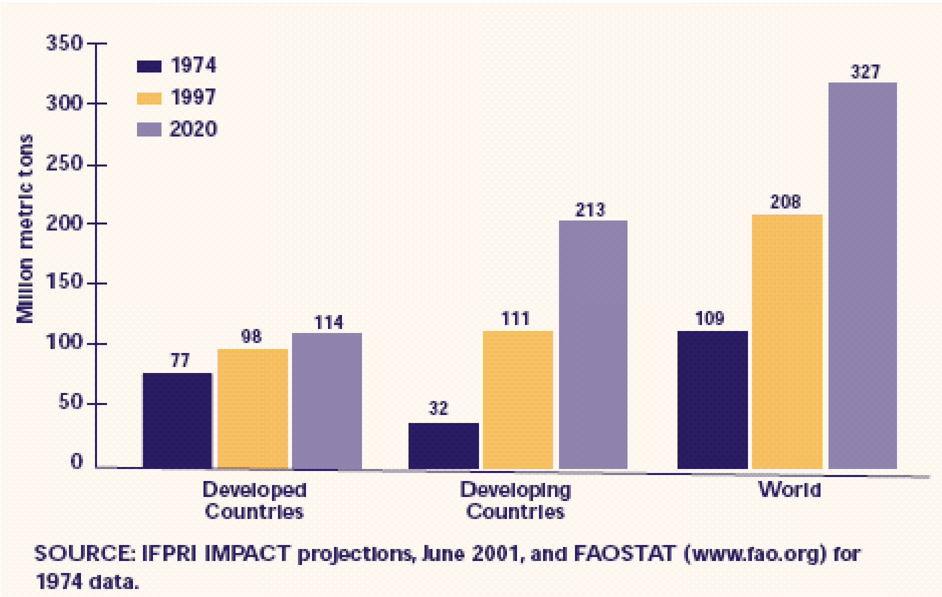
5 The developing world includes India, China, West Asia/North Africa, Other Asian developing countries, Latin America and Sub-Saharan Africa.

Figure 8 Development of demand for cereals



Source: Rosegrant, 2001.

Figure 9 Development of demand for meat



Source: Rosegrant, 2001.

2.3.2 Land use for Wood

Wood has many applications, as it is used as fuel, as timber (roundwood, sawnwood, panels), and it is processed to for example fiberboard and paper. Due to a growing population the demand for wood increases. Sources of wood can be both natural forests (a large part of the wood used for fuel is taken from existing forest) and plantations.

Forest plantations account for only a very small proportion of the global forest area. Whilst total forested land is estimated at 3.87 Gha (FAO, 2003), or almost 30% of the global land area, forest plantations only account for about 4% of this total forest area (FAO, 2006). About 78% of these plantations are productive, i.e. established for wood and fibre production. 22% are mainly protective, for conservation of soil and water. In 2005, the total area of productive forest was about 109 million ha. The area of productive forest plantations increased by about 2.5 million ha during 2000-2005, 87% of which are productive forest plantations. All regions show an increase in plantation area, but the highest plantation rates are found in Asia, particularly in China (FAO, 2006).

About 40% of the total wood removals from forests are due to the demand for fuel[6] (either as fuelwood or as charcoal). This is mainly (over 75%) consumed by Asia and Africa - 88% of wood removals in Africa is used as fuelwood. In Africa wood is still the most important source of household energy, used mainly for cooking, although cottage industries (such as food drying and brick-making) also consume significant volumes in some countries. Fuel wood consumption is mainly determined by income, availability of wood supplies and availability of alternatives. As consumers become wealthier they tend to use other forms of energy, particularly electricity and liquid fuels. So while an increasing population causes an increasing overall consumption of fuel wood, per capita consumption is declining. In most countries there is a surplus of fuel wood, although there is often localized scarcity. In some cases, increasing electricity and gas prices have resulted in a switch back to fuel wood. Therefore dramatic changes in fuel wood are unlikely till 2015 The shift towards alternative fuels may accelerate beyond 2015, depending on developments of infrastructure and on improvements in the efficiency and cost-effectiveness of generating energy (FAO, 2003).

Regarding fiber and paper, these can be produced from a variety of different sources, including pulpwood (from forests, other wooded land and trees outside forests), wood residues (from the sawmilling and plywood industry and recovered wood products), non-wood fibre sources (such as grasses and bagasse), and recovered paper (FAO, 2005).

Table 2 and Figure 10 present the demand of wood and the corresponding area of forest plantations, as estimated in the various literature sources analyzed.

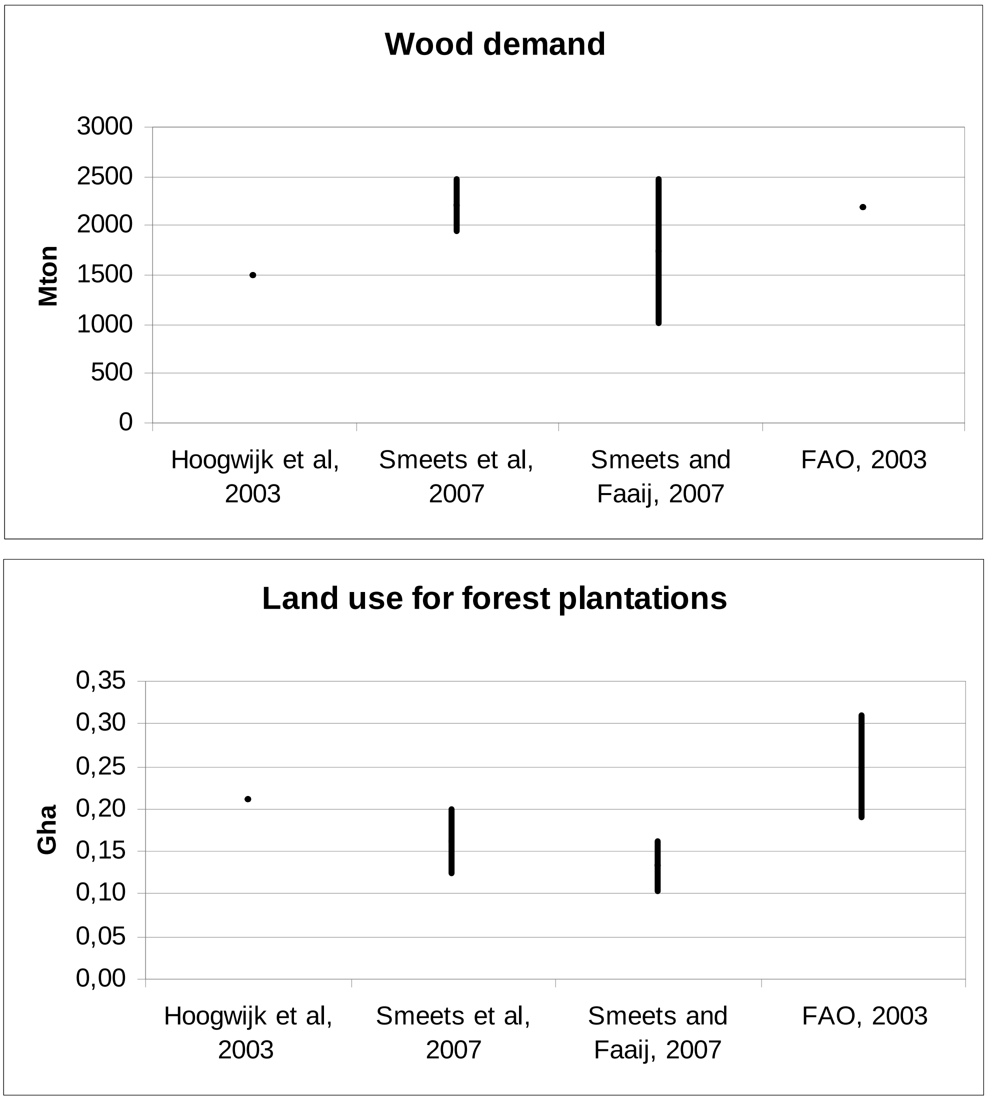
[6] Note that these are data based on country reports to the FAO. Due to limited monitoring and reporting of fuelwood removal, the total volume of fuelwood is expected to be much higher in reality (FAO, 2006)

Table 2 An overview of the results on global wood demand in the literature analysed

Source	Base year and demand (Mton)	Year of study and potential demand (Mton)	Demand 2020 (Mton) (linear interpolation)	Land use 2020 (Mha)
Hoogwijk et al., 2003	2003 Total wood: 350	2050 Total wood: 1,756	Total wood: 1,490	Total wood: 211
FAO, 2003	2000 Roundwood: 870 Fuel wood: 972 Total wood:	2030 Roundwood: 1,392 2015 Fuel wood: 972	Roundwood: 1,220 Fuel wood: 972 Total wood: 2,192	Total wood: 190-310[1]
Smeets et al., 2007	1998 Roundwood: 870 Fuel wood: 986 Total wood: 1856	2050 Roundwood: 1,102-1,798 Fuel wood: 986-1,508 Total wood: 2,088-3306	Roundwood: 969-1,264 Fuel wood: 986-1,206 Total wood: 1,955-2,471	Total wood: 124-200
Smeets and Faaij, 2007	2002 Roundwood: 928 Fuel wood: 1044 Total wood: 1972	2050 Roundwood: 1,102-1,798 Fuel wood: 986-1,508 Total wood: 2,088-3,306	Roundwood: 993-1,254 Fuel wood: 1,022-1,218 Total wood: 2,015-2,472	Total wood: 103-163

[1] Own estimations on basis of FAO, 2003.

Figure 10 Global demand of wood (Mton), and land use for forest plantations, in 2020



The estimates differ significantly, with the striking result hat Hoogwijk et al. (2003) assume the *lowest demand* of wood and estimate one of the *biggest areas* of forest plantations. Reason for the differences between the studies is the approach they followed, and, most notably, in the extent to which wood was assumed to be used for non-energy purposes. The work done by Hoogwijk et al. (2003) was aimed at assessing the available bio energy potential. To achieve this, a certain wood demand was assumed, which was converted to corresponding land with an estimate of the yield of forest plantations. Wood from natural forests, trees out of the forest and waste wood was all assumed to be used as input for bio energy production. In the other studies much less bio energy demand was assumed so that wood for non-energy purposes could be taken from both forest plantations and other types of forest and trees..

Although FAO (2003) does not give an estimate for the future area of forest plantations, a minimum and maximum can be deduced using historic yield factors. In 2000 190 Mha provided 232 Mton of wood. In 2020 forest plantations will produce 387 Mton wood, assuming no improvements in production efficiency this means 310 Mha of forest plantations. The report emphasizes however that technical improvements lead to increasing yields. Therefore, the area of forest plantations in 2020 will be somewhere between 190 and 310 Mha according to FAO (2003).

Because studies vary significantly from each other it is difficult to accurately predict future land use for forest plantations, but we conclude from the bottom graph in Figure 10 that it is expected to be somewhere between 100 and 300 Mha.

In a paper by Nilsson and Bull for the FAO (Nilsson, 2005), it is argued that future developments in the demand and supply for wood (and thus forest land) are highly uncertain, as these depend significantly on a number of issues that have changed rapidly in recent years. In their paper, a large range of recent developments relevant to this area are discussed:

- Demand growth in emerging economies such as China and India.
- Increased illegal logging.
- Over harvesting of existing forests (in important supply countries).
- A downward trend in available supply from existing forests.
- Environmental demands.
- Increasing fuelwood demand in many developing countries.
- Increasing competition for wood fibers between the energy industry and the traditional forest industry.
- Increasing rate of natural disturbances that is reducing the forest capital.
- Rapid technological and biotechnological developments.
- Increased use of recovered paper.
- Policies.
- Increased substitution.
- More efficient industrial processes.
- Etc.

Nilsson thus concludes with the recommendation to develop a revised wood supply and demand analysis. Without going into detail on all of these issues, we briefly discuss the first issue, the demand for wood products in emerging economies, in the text box below.

Booming consumption in emerging economies
Based on (FAO, 2003) and (Nilsson, 2005)

In China, India and other Asian economies with high growth rates, wood consumption rises dramatically. Demand growth in these countries may thus have a significant effect on the global wood market and trade. At present, around 40% of the world population live in China and India, but they consume less than 10% of the world's industrial wood. Other developing countries such as Indonesia, Brazil, Bangladesh and Nigeria also all have large populations, but relatively low per capita rates of industrial wood consumptions.

The following can illustrate this. The total consumption of industrial roundwood in China is currently around 270 million m^3 (± 157 Mton), and imports have increased in the past five years from 5 million to 25 million m^3 (14.5 Mton). Total import of forest products, expressed in roundwood equivalents (RWE), has skyrocketed from 40 million m^3 in 1997 to 120 million in 2004 (70 Mton). Since China is expected to be able to sustain an annual growth of 7-8% for at least another decade, the consumption of forest products is bound to increase further in the future. As it is estimated that China is already over harvesting substantially - currently some 120 million m^3/year - China´s imports can be expected to increase in the future.

Economic forecasts for India are quite similar, with economic growth expected to be 6.5-7%/year. Estimates for industrial log consumption in India show that it may increase from the current 50 million m^3, to 90-120 million m^3 (52 Mton) in 2020.

Economic growth in Latin America is expected to be about 4-5% in the near future. Demand for industrial roundwood in that region is predicted to increase from 120 m^3 in 1990, to 200-220 million m^3 (116-128 Mton) in 2020.

It should be noted that, due to lack of transparent information and often contradictory information in these countries, the uncertainties in these data are very large.

2.3.3 Land use for bio energy

According to Domburg (2008), biomass is currently the most important renewable energy source, providing about 10% (46 EJ) of the annual global primary energy demand of 489 EJ (2005). A major part of this biomass use (37 EJ) is non-commercial, and relates to charcoal, wood and manure used for cooking and heating. Modern bioenergy use for industry, power generation or transport fuels is making already a significant contribution of 9 EJ, and this share is growing.

A significant part of this bioenergy is extracted from forests. As can be seen from Table 2 above, around 1000 Mton of wood (20 EJ) is used annually, mainly on a small (household) scale, for cooking. Future utilization of fuel wood may decrease because of a growing economy causing a shift towards liquid fuels and electricity. In the future however, biomass will also be used more and more in the large scale production of biofuels and electricity.

It is difficult to predict how much bioenergy will be used in the future, among other things because bioenergy policies are changing rapidly in recent years, often driven by climate policies, high oil price or security of supply considerations.

In the RFA substudy by E4tech, global biofuel demand is analysed using various scenarios. These assume a use of biofuels ranging from 3.9-11 EJ in 2020 - their data are discussed in more detail in the next paragraph. OECD-FAO (2007) predicts 3.2 EJ from biofuels in 2020 (linear interpolation from 2016) in the US, EU, Canada, China and Brazil.

There are a number of studies aimed at estimating the biomass potential for certain scenarios - which is, of course, different from an actual forecasting study. Ranges in these predictions are very large because there are a lot of parameters to be varied and uncertainties, including trends in land demand for food production (depending on population growth, economical growth, diet, etc.), developments in agricultural yields and technology (incl. irrigation), future availability of agricultural land (among other things depending on environmental policies) and developments of processing technologies for biomass (eg second generation biofuels).

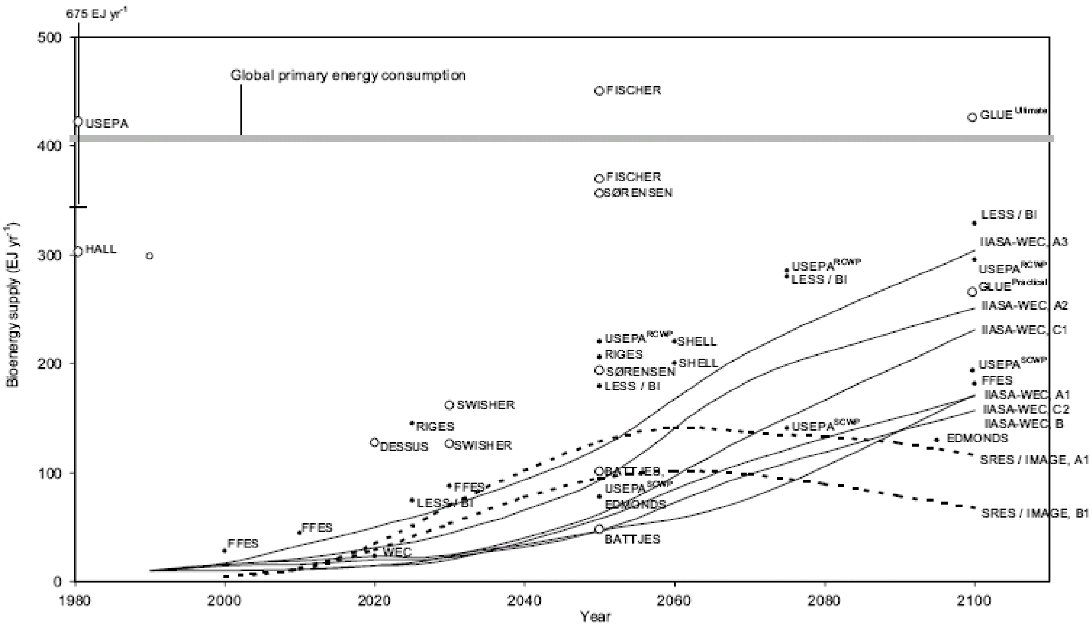
Hoogwijk et al. (2003), for example, estimate that 35-1135 EJ of primary energy from biomass could be available in 2050. The range is mainly caused by the availability of surplus land.

- For the lower estimate it is assumed that no surplus land is available, because all land is used for food production.
- For the higher estimate it is assumed that 2.6 Gha of surplus land is available for energy crops resulting in 988 EJ per year.

Fischer and Schrattenholzer (2001) estimated a potential of 370-450 EJ in 2050. In the lower as well the higher estimate, most potential is provided by energy crops and wood. Furthermore they made a survey of studies on future bioenergy potential, which results in a range from 91 to 675 EJ per year. Comparing results is, however, difficult because of differences between time horizons and assumptions. Berndes et al. (2003) reviewed 17 studies, their results are presented in Figure 11. Estimates for 2050 range from below 100 EJ to around 450 EJ. Very recently, a comprehensive assessment of global biomass potential estimates was written by (Domburg et. al, 2008).[7]

[7] This study has not yet been published.

Figure 11 Potential biomass supply for energy over time[8]



Source: Berndes et al.,2003.

2.3.4 Land use for biofuels

The main biofuel producers of 2006 are listed in Table 3. Clearly, the global ethanol production is currently much higher than biodiesel production, mainly due to the high production volumes in the USA and Brazil. Historically, since the 1970s, Brazil has been the worlds largest ethanol producer, but the ambitious US ethanol policies of the past few years have caused the US to increase its ethanol production rapidly in only a few years. Regarding biodiesel, Germany is the leading producer, together with several other EU countries. In 2006, The EU accounted for 75% of the world´s biodiesel production, and only 4% of the global bioethanol production. Clearly, as the scenarios by E4Tech show, the biofuels demand is expected to increase significantly in the next decade.

8 Resource focused studies are represented by hollow circles and demand driven studies are represented by filled circles. USEPA and HALL, who do not refer to any specific time, are placed at the left side of the diagram. IIASA-WEC and SRES/IMAGE are represented by solid and dashed lines respectively, with scenario variant names given without brackets at the right end of each line. The present approximate global primary energy consumption is included for comparison.

Table 3 Biofuel production (in Mton) of the Top 25 biofuels producing countries (in 2006), and total biofuel production in the EU and globally

	Country	Ethanol (Mton)	Biodiesel (Mton)
1	United States	14.46	0.75
2	Brazil	13.83	0.06
3	Germany	0.40	2.46
4	China	0.79	0.06
5	France	0.20	0.55
6	Italy	0.10	0.50
7	Spain	0.32	0.12
8	India	0.24	0.03
9	Canada	0.16	0.04
9	Poland	0.09	0.11
9	Czech Republic	0.02	0.13
9	Colombia	0.16	0.05
13	Sweden	0.11	0.00
13	Malaysia	0.00	0.12
15	United Kingdom	0.00	0.10
	EU Total	1.26	3.96
	World Total	30.81	5.28

Source: REN21, RENEWABLES 2007 GLOBAL STATUS REPORT, http://www.martinot.info/RE2007_Global_Status_Report.pdf.

These production rates have now been converted to estimates for current land use for biofuels. For this calculation, it was assumed that

- Biodiesel in the EU was produced from rapeseed, in the USA from soy beans, and in China and Brazil from palm oil.
- Bioethanol in the EU was produced from cereals (62%) and sugar beet. In 2006, a considerable amount, roughly 16%, was produced from wine alcohol sold at the Commission’s auctions. In the US, it was assumed to be produced from corn, in Brazil from sugar cane, and in China from wheat.
- Conversion factors of the biofuel production processes (relating kg biofuel to kg harvested crop) were taken from the most recent draft of the Dutch CO_2 tool[9].
- Yield data were taken from ADAS estimates for the relevant crops and regions, for 2010.

The results of these calculations are shown in Table 4, for three of the main biofuel producing countries and the EU, which in total covers 98% of the global ethanol production, and 92% of the global biodiesel production. Total land use for these biofuels was in 2006 about 16.5 Mha, of which a large share was for US and EU biofuel production. As a large share of the global biodiesel production is from rapeseed grown in the EU (with relatively low yield per hectare, compared to sugar or palm oil), the land use share of biodiesel larger than its share in the total production (29% versus 15%).

9 Not yet published.

Table 4 Current land use of biofuels of the four main producers (estimate for 2006), in Mha

	Bioethanol	Biodiesel	Total biofuels
EU	0,4	3,1	3,6
USA	5,4	1,6	7,1
Brazil	2,5	-	2,5
China	0,6	0,0	0,6
Total for these 4 regions	9,0	4,8	13,8

Our forecasts for global demand for feedstock and land for biofuels production are based on the outcome of the scenarios developed by E4Tech in the framework of this study for the RFA. For an explanation of the rationale and assumptions behind these scenarios and land use calculations, we refer to the E4Tech report.

Table 5 provides an overview of the global feedstock demand for biofuel production in 2010 and 2020, for the various scenarios. A comparison of this demand with the global production of 2006 of these crops is shown in Table 6. In all scenarios, sugar cane will be the main feedstock (in Mton), requiring a very significant increase of current production levels. In scenarios 1 and 2, this is followed by maize, wheat, soy, palm and oilseed rape, in scenarios 3 and 4 it is followed by palm, sorghum, jatropha and soy. Clearly, these biofuel scenarios will have a significant impact on the total demand for these commodities, especially for cassave, sugar cane, sorghum, soy and palm oil. Scenarios 2 and 4 also use significant amounts of wood and agricultural residues.

The variation in feedstock demand between the various 2020 scenarios is quite large. As scenarios 1 and 2 assume much less global biofuel demand than scenarios 3 and 4, the total demand for feedstock in these scenarios is less, too. In the period 2010 to 2020, demand on all feedstocks considered here is expected to increase.

In these scenarios, biofuels producers are expected to buy a significant part the total global supply in a number of feedstocks in 2020 - in other words, production of a number feedstocks needs to be increased significantly to supply the amounts of feedstock required for biofuel production. Production of palm, sugar cane, oilseed rape and soghum needs to be increased significantly in all scenarios, although the extent varies between scenarios. It can also be noted that a significant increase (of 24-40%) of use of wood and agricultural residues is expected in both of the scenarios with 2nd generation biofuels (scenarios 2 and 4). In the period 2010-2020, global demand increases of wheat, sugar beet, maize and soy are expected to be limited to max. 20% of the 2006 production volume.

These strong demand increases will significantly affect the market of some of these commodities. If their production is not increased fast enough (in line with biofuels and perhaps also food demand increase), price increases can be expected. These may then cause the biofuels (and food) industry to revert to other, then cheaper crops, changing the biofuels feedstock mix from what we would expect now.

The impact of 2nd generation biofuels can be seen when comparing scenarios 1 with 2, and 3 with 4 (2 and 4 being comparable to 1 and 3, except that in 2 and 4 a share of 2nd generation biofuels is assumed): global feedstock demand (in Mton) is reduced by about 20 and 30% respectively.

Table 5 Global feedstock demand for biofuels in 2010 and 2020 (in million tonnes)

Crop	2010 proposed targets	2020 Scenario 1 (low 2G)	2020 Scenario 2 (high 2G)	2020 Scenario 3 (low 2G)	2020 Scenario 4 (high 2G)
Cassava	15	40	31	72	55
Wheat	37	111	62	90	38
Sugar beet	1	2	2	31	19
Sugar cane	298	1,100	686	1,799	962
Sorghum	5	24	17	302	155
Maize	72	149	67	67	28
Soy	31	90	63	107	82
Palm	24	82	62	386	308
Sunflower	1	3	1	0	0
Jatropha	0	8	24	147	124
Oilseed rape	22	56	33	88	69
Bagasse	0	0	32	0	36
Wood residues	0	0	129	0	142
Agricultural residues	0	0	165	0	183
Total:	**505**	**1,667**	**1,373**	**3,090**	**2,201**

Source: E4Tech. Scenarios 2 and 4 are the high 2G scenarios.

Table 6 Global production of the biofuel feedstock crops in 2006 (in million tonnes), and percentage of these amounts required for the biofuel scenarios.

Crop	Global feedstock production in 2006	2010 proposed targets	2020 Scenario 1 (low 2G)	2020 Scenario 2 (high 2G)	2020 Scenario 3 (low 2G)	2020 Scenario 4 (high 2G)
Cassava	226	6%	18%	14%	32%	24%
Wheat	604	6%	18%	10%	15%	6%
sugar beet	256	1%	1%	1%	12%	7%
Sugar cane	1,391	21%	79%	49%	129%	69%
Sorghum	56	8%	43%	30%	536%	274%
Maize	694	10%	21%	10%	10%	4%
Soy	428	7%	21%	15%	25%	19%
Palm	231	10%	36%	27%	167%	133%
Sunflower	31	5%	10%	3%	0%	0%
Jatropha	0	-	-	-	-	-
Oilseed rape	89	24%	63%	37%	99%	78%
Bagasse	209	0%	0%	16%	0%	17%
Wood residues	354	0%	0%	36%	0%	40%
Agricultural residues	694	0%	0%	24%	0%	26%
% of global total feedstock of these products in 2006		**10%**	**32%**	**26%**	**59%**	**42%**

Source: E4Tech. Scenarios 2 and 4 are the high 2G scenarios.

Table 7, Table 8 and Table 9 illustrate what these results mean in terms of hectare land required, for different yields supplied by ADAS (as part of their work for the RFA). Bagasse, wood and agricultural residues are assumed not to require any additional land since they are assumed to be by products of existing agriculture/forestry.

From these tables, we can conclude that an additional 73 to 276 Mha agricultural land will be required, depending on the scenario, the yield development and the amount of 2nd generation biofuels available. Scenario 2 requires the least land, scenario 3 the most.

The impact of 2nd generation on land use is even more profound than on Mton feedstock in case of scenarios 1 and 2: land demand is about 40% less in scenario 2, compared to scenario 1. In case of scenarios 3 and 4, the impact of 2nd generation biofuels on land use is comparable to the impact on Mton, a 30% reduction.

Comparing the results of the high yield with the BAU yield results, we can see that the global land use of biofuels in case of the high yield is 11-12% lower than in the BAU yield case. The low yield scenarios require 20-26% more land than the BAU yield results. It should be noted, however, that especially in scenarios 3 and 4 the uncertainties of the low yield land use estimate are quite large. This is due to the relatively large share of jatropha in the feedstock mix of these scenarios. As this crop is not yet cultivated on a large scale, there is currently no commercial yield data available, leading to large uncertainties regarding future yields.

Even though sugar cane was the largest feedstock in terms of Mton in all scenarios, its land use is relatively limited due to its high yield. Relatively large areas are required for soy and oil seed rape production, and jatropha in scenarios 3 and 4.

Table 7 Global estimated land area required for the production of the biofuel feedstock in 2010 and 2020, for the **high yield** estimate (in million hectares)

	2010 Proposed targets	2020 Scenario 1 (low 2G)	2020 Scenario 2 (high 2G)	2020 Scenario 3 (low 2G)	2020 Scenario 4 (high 2G)
Cassava	0.9	2.0	1.6	3.3	2.5
Wheat	9.2	28.9	16.1	25.5	11.1
Sugar beet	0.0	0.0	0.0	0.4	0.3
Sugar cane	4.1	12.6	7.9	21.0	11.7
Sorghum	0.2	1.0	0.7	10.4	5.3
Maize	8.6	14.2	6.5	7.1	3.4
Soy	11.4	38.4	22.0	46.3	37.1
Palm	1.3	3.2	2.4	16.9	13.5
Sunflower	0.8	1.5	0.6	0.0	0.0
Jatropha	0.0	1.3	4.0	25.5	21.4
OSR	6.6	19.0	11.0	38.5	32.2
Bagasse	0.0	0.0	0.0	0.0	0.0
Wood residues	0.0	0.0	0.0	0.0	0.0
Agricultural residues	0.0	0.0	0.0	0.0	0.0
Total (Mha)	**43.2**	**122.3**	**73.0**	**195.5**	**139.1**

Source: E4Tech, ADAS.

Table 8 Global estimated land area required for the production of the biofuel feedstock in 2010 and 2020, for the **estimated yield** estimate (in million hectares)

	2020 Scenario 1 (low 2G)	2020 Scenario 2 (high 2G)	2020 Scenario 3 (low 2G)	2020 Scenario 4 (high 2G)
Cassava	2.3	1.7	3.7	2.7
Wheat	32.4	18.0	29.2	13.0
Sugar beet	0.0	0.0	0.5	0.3
Sugar cane	14.1	8.8	23.5	13.1
Sorghum	1.1	0.8	11.7	6.0
Maize	15.9	7.3	7.9	3.8
Soy	43.0	24.7	51.9	41.6
Palm	4.3	3.2	22.0	17.6
Sunflower	1.7	0.7	0.0	0.0
Jatropha	1.5	4.5	28.4	23.7
OSR	21.5	12.5	43.3	36.2
Bagasse	0.0	0.0	0.0	0.0
Wood residues	0.0	0.0	0.0	0.0
Agricultural residues	0.0	0.0	0.0	0.0
Total (Mha)	**137.8**	**82.3**	**221.9**	**158.0**

Source: E4Tech, ADAS.

Table 9 Global estimated land area required for the production of the biofuel feedstock in 2010 and 2020, for the **low yield** estimate (in million hectares)

	2020 Scenario 1 (low 2G)	2020 Scenario 2 (high 2G)	2020 Scenario 3 (low 2G)	2020 Scenario 4 (high 2G)
Cassava	2.5	1.9	4.2	3.2
Wheat	37.7	21.2	34.6	15.9
Sugar beet	0.0	0.0	0.5	0.3
Sugar cane	16.8	10.5	28.1	15.8
Sorghum	1.9	1.3	15.2	8.7
Maize	19.5	8.9	9.9	4.9
Soy	50.3	31.6	60.8	48.9
Palm	5.0	4.3	24.9	19.9
Sunflower	2.0	1.5	0.0	0.0
Jatropha	2.2	1.6	41.7	34.9
OSR	27.7	18.7	55.8	46.6
Bagasse	0.0	0.0	0.0	0.0
Wood residues	0.0	0.0	0.0	0.0
Agricultural residues	0.0	0.0	0.0	0.0
Total (Mha)	**165.7**	**101.4**	**275.7**	**199.0**

Source: E4Tech, ADAS.

Land use effect of co products

Biofuels production from wheat, maize and rapeseed produces co products like meal and DDGS, that can be used as animal fodder. In that case, less feed crops need to be grown, reducing the agricultural land use for feed. It is shown in the RFA study on co products (CE, 2008) that these by products can then reduce the land use of biofuels significantly in the biofuel scenarios analysed here. The land use compensation of co products depends on the scenario, and is shown in Table 10 (for the 'expected' yield).

Table 10 Reduced land demand for feed crops, if co products are used as feed (in Mha)

2020 Scenario 1 (low 2G)	2020 Scenario 2 (high 2G)	2020 Scenario 3 (low 2G)	2020 Scenario 4 (high 2G)
31.0	16.7	29.1	17.5

Source: (CE, 2008).

These figures may not be much compared to the global agricultural land area of 5 Gha (5.2-5.7 Gha in 2020), but the effect on the land use of the various biofuels scenarios analysed here is significant. Use of co products as animal feed reduces the land use in scenarios 1 and 2 by 20-25%, and in scenarios 3 and 4 by 11-15%.

2.3.5 Land use for other products

Next to food, wood and energy, biomass can be used to produce several other products e.g. textiles, rubber and petrochemicals. Their share in total biomass production and land use is small, therefore not much literature has been found on this subject. Hoogwijk et al. (2003) however, estimated the demand and land use for rubber, cotton and petrochemicals. Table 11 presents their results.

Table 11 Global land use for other products, as found in the literature

Product	Demand 2003 (Mton)	Demand 2050 (Mton)	Demand 2020 (Mton)	Land use 2020 (Mha)
Rubber	7	31	16	8
Cotton	20	142	64	3.2
Petrochemicals	200	398	272	0–4

NB. The data on petrochemicals is total demand, i.e. not of biomass based petrochemicals. Hoogwijk, (2003) assumes that the market share of biomass based petrochemicals could increase to 5-100% in 2050. We assume here that this range could be 0-10% in 2020.

2.4 Key uncertainties

- Only a relatively limited number of studies are concerned with forecasting developments in various drivers for feedstock and land. In recent years, global forecasts that also looked at land use were made by UNEP and the FAO, and by the Dutch Copernicus institute (Hoogwijk 2003, Smeets 2007, partly carried out for the IEA). Especially the latter studies are aimed at developing a number of scenarios, illustrating the range of potential future land use by determining the maximum potential for bioenergy production in a number of scenarios for food, feed, agricultural intensification, etc. The range in results between various scenarios are very significant.
- Even though various estimates for wood demand are quite similar, large differences appear when these are converted to land demand for forests (wood plantations). Studies seem to differ in the assumed amount of wood that can be taken from natural forests (partly due to different assumptions regarding bioenergy use of this waste wood), and in the future estimates of yields of forest plantations.
- As Nilsson (2005) points out, existing forecasting studies on wood demand and land use are highly uncertain, due to many recent developments.
- Most forecast studies do not focus on 2020, but rather provide results for another year (often, for 2050). Due to the time constraint of the study, these results were converted to 2020 using linear interpolation. This may lead to errors, as both drivers and agricultural developments may not develop linearly, but may, for example, show accelerated growth in the short or medium term.
- Land use is highly dependent on crop yields, and thus on (global and regional) agricultural developments and intensification. In the past decades, yield improvements have, to a large part, compensated the growth in food demand. As the substudy by ADAS shows, there is quite an uncertainty in the yields to be expected in the various world regions. This can be expected to reflect on the demand for future agricultural land.

- Furthermore, developments in population growth and, especially, global diet, which is difficult to predict as it depends on many variables such as economical growth and policy development, have a very profound effect on demand for cropland and pastures.

2.5 Conclusions

Food and feed production are the main sources of demand for agricultural land: in 2006, about 5 Gha of land is in use for croplands and pastures. Pastures have a large share in this, about 3.4 Gha, the remainder is used as arable land (1.4 Gha) or for permanent crops (0.14 Gha). Since 1990, the global forest was reduced (80 Mha), whereas arable land and the area used for permanent crops increased (34 Mha in total). No less than half of the agricultural area is currently used for cereals production (674 Mha), 21% is used for oil crops (287 Mha).

Future food and feed land demand depends on population growth, economical growth, global diet (meat consumption, in particular), government policies and on developments in agricultural yield and technology. The current trend in global diet is an increase in meat consumption, which has a profound effect on the demand for cropland.

Models expect that the demand for agricultural crops for food and feed will increase significantly in the next decades. This increase in demand is mainly met by an increase of agricultural yields due to agricultural intensification and technology improvement, more efficient meat production and crop improvements. Despite these improvements, demand growth is expected to be so high in next decades, that the agricultural land demand for food and feed is expected to grow by 200-500 Mha until 2020. Compared to the agricultural land increase since 1990 (34 Mha), this is very high.

Currently second largest driver for land demand is the wood, pulp and paper industry. Wood is used for timber and paper production, and demand for these products is increasing strongly. It is also a large bioenergy source, as many households all over the world use waste wood from forests for heating and cooking. About 4% of the global forest area is plantation forest, this area is increasing steadily. It is estimated that the area of forest plantations in 2020 will be somewhere between 190 and 310 Mha. However, uncertainties in these predictions are large, due to strong growth of wood consumption in emerging economies, but also due to other developments such as increasing environmental demands.

Accurate forecasts for global land use for bioenergy in 2020 are lacking, but various studies assess the future bioenergy *potential*. Ranges in results are very large, and mainly depending on the assumptions and scenarios used regarding agricultural developments.

Current biofuels production (2006) uses about 13.8 Mha agricultural land, mainly due to biofuels production in the USA, the EU, Brazil and China. As biofuel demand will rise in the future, this land use will increase significantly, as the biofuel scenarios developed by E4Tech in this RFA study show. They result in a land use in 2020 that varies between 73 and 276 Mha, depending on

- The global biofuel demand.
- The feedstock mix, i.e. whether or not high yield crops are used, and the share of 2nd generation biofuels that are produced from agricultural and wood residues.
- The agricultural yield of these crops in 2020.

If the co products of the biofuels production from wheat, maize and oilseed are used as animal feed, this will partly compensate the land demand for biofuel crops. Land demand of the various scenarios can then reduce by 10-25%, depending on the feedstock mix used.
In these scenarios, the production (and thus area) of a number of crops needs to be increased significantly, compared to current production levels. In all scenarios, sugar cane is the main feedstock, requiring significant expansion of current production. Depending on the scenario, production of other major feedstocks such as maize, palm, soy, jatopha, wheat and rapeseed oil need to be increased significantly as well.

As the demand for land for food, feed, wood and bioenergy is expected to increase further in the next decade, agricultural land area is predicted to increase further even without additional biofuels demand. This will result in land change, most likely at the expense of forest and, perhaps, pastures and meadows. The statistics on fallow land are currently incomplete, and as we can see in the next chapter, this is also the case for idle land. However, availability of these types of land seem to be limited, and insufficient to accommodate the demand increase. We can thus conclude that the biofuels demand increase will require additional agricultural land.

3 Global agricultural land availability

3.1 Introduction

In the following chapter , the global agricultural land availability is assessed, with a focus on 2020. An overview of the literature used for this analysis (including information on the drivers analysed, methodologies used, and results) can be found in Annex B.

There is quite some overlap between this chapter and the previous one, since actual use of land is strongly determined by the demand for feedstock.

3.2 Key findings

In the last few years, several studies were conducted to estimate the total amount of available land for food production in the world in the near future. The overall conclusion of the larger part of the studies is that there will be no shortage of land or water for irrigation on a global level to produce the required food. On a regional level though, serious problems will persist.

3.2.1 Overview

All studies agree more or less in the current land use in the world. Approximately 1.5 Gha is used as arable crop land and 3.5 Gha used as pasture. The total use as forest ranges between 3.9 and 4.7 Gha.

The studies analyzed can be divided into two categories: estimations based on scenarios (demand driven/interchangeability of types) and estimations based on current (technological) potentials and usage. The first allow an exchange between for example crop land and forest, the later ones estimate the surplus agricultural area while the other land uses remain equal.

The outcome of the studies are very different. For the year 2050, the available agricultural land ranges between 0 and 3.7 Gha. In Table 12 an overview is given of the studies and a linear estimate is made for the year 2020.

Table 12 An overview of the literature on global agricultural and forest land availability

Source	Base year and use (Mha)	Study of year and potential change (Mha)	In 2020 (Mha) (linear interpolation)
UNEP 2007	**2000** • Cropland and pasture: 4,920 • Forest: 4,700	**2025** • Cropland and pasture: +440-990 • Forest: -/- 340-570	**2020** • Cropland and pasture: +350-790 • Forest: -/- 270-460
MNP 2007		**2020** • Cropland and pasture: +0-600	**2020** • Cropland and pasture: +0-600
CE Delft 2007	**Current** • Cropland: 1,500 • Pastures: 3,500 • Forest: 3,900	**2020** • Cropland: +200 • Pastures: 0 • Forest: -200	**2020** • Cropland: +200 • Pastures: 0 • Forest: -200
Smeets et al. 2007	**Current** • Cropland and pasture: 5,000 • Forest: 3,900	**2050** • Cropland and pasture: +729-3,585	**2020** • Cropland and pasture: +290-1,400
Hoogwijk et al. 2005	**1970** • Cropland: 3,000 • Forest: 3,000	**2020** • Cropland: +0-800 • Forest: +100-300	**2020** • Cropland: +0-800 • Forest: +100-300
FAO 2002	**Current** • Cropland: 1,500 • Pastures: 3,460 • Forest: 3,870	**2030** • Cropland: +1,120	**2020** • Cropland: +750
Hoogwijk et al. 2003	**Current** • Cropland: 1,500 • Pastures: 3,500 • Forest: 4,000	**2050** • Cropland: +0-3,700 • Degraded: +430-580	**2020** • Cropland: +0-1,480 • Degraded: +170-230
Fischer et al. 2000	**1990** • Cropland: 1,520 • Pastures: 3,380 • Forest: 3,980	**2050** • Cropland: +220 • Pastures: -/- 80 • Forest: -/- 110	**2020** • Cropland: +90 • Pastures: -/- 30 • Forest: -/- 45

3.2.2 Land types

There are several explanations for the large differences between the studies. Not only the type of scenario (demand driven or technology driven) but also the detail in which the study is performed. Some studies for example make a distinction between land types and others only refer to the total arable land or agricultural land. In this paragraph this distinction will be explored in more detail.

Cropland

During the last 20 years, the exponential expansion of cropland has slackened, but land is now used more intensively. Globally in the 1980s on average a hectare of cropland produced 1.8 tonnes, nowadays it produces 2.5 tonnes (UNEP, 2007). The current global use of cropland is about 1.5 Gha, this is approximately 11% of the world's surface area. The primary function of cropland is the production of food and feed (fodder).

The studies show very different forecasts of the development of the available area for cropland. The outcomes range between 0 - 1,480 Mha. Especially the studies of Hoogwijk et al. (2003, 2005) and Smeets et al. (2006) predict a very large increase of the available cropland in 2020. These studies estimate the available land by determining the surplus land due to an increase in yield per hectare and (for the high end of the range) very significant technological advancements. This results in an increased use of formally low-productive land and a lower demand of the current cropland use. It should be noticed that these studies do not make a distinction between cropland and pastures. The smallest changes are predicted by Fischer et al. (2000).

The differences in the outcomes can be explained by the different variables used in the models. Used variables are the availability of water, the increased yield, technological advancements (e.g. biotechnologies), sustainable agriculture, land degradation (erosion, desertification, pollution) and climate change.

Pastures

Pastures are primarily used for grazing livestock for the production of meat and dairy. With an area of about 3.5 Gha it uses more than twice the area under arable and permanent crops.

In most studies pastures and cropland are taken together in the estimated changes for the future, because both land uses are needed to provide food and feed for humans and animals. An accurate estimate of the increase of pastures is not presented in the studies, but with the rising average meat and dairy consumption in the world it is most likely that the total area of pastures will grow as well.

A development which counteracts the increased area needed for grazing is the more intensive system of stall-feeding. In this system fodder is cut an brought to the stabled animals. This leads to less soil damage and less demand for land. Smeets (2007), for example, considers landless production systems in their future land use scenarios. The pastures that then become available can then be used for crop production, if suitable. Smeets also concludes that 35% of the global area of land suitable for crop production is currently covered by permanent pastures and arable land for fodder crops (1.37 Gha). Especially in sub-Saharan Africa, Oceania and the Caribbean and Latin America, large areas suitable for crop production are currently used as pastures: 60%, 49% and 42% of the total area suitable land, respectively, in 1998.

Forest

The 2005 Global Forest Resource Assessment (FAO, 2005) estimated that the world's total forest area in 2005 was 3.952 Gha. The estimate of the global area of forest plantations in 2005 is 139.8 Mha, or approximately 3.5% of the estimated global forest area in 2005. In 2000 about 30% of the worlds surface was covered by forests, of which 56% were tropical and subtropical.

Overall, the studies predict a decrease of the area used by forests. During the 1990s the total forest area shrank by a net 9.4 Mha each year, but this rate of deforestation will probably slow down in the coming decades.

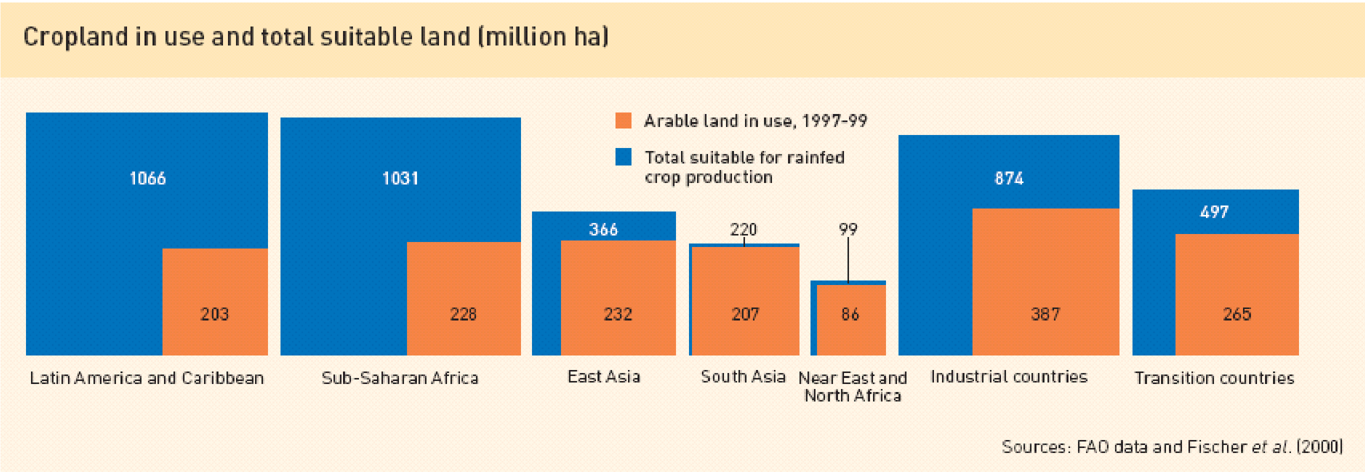
Smeets, 2007, states that about 24% of the global area of land suitable for crop production is currently covered by forests, which amounts to 900 Mha. Almost

80% of this area is located in the Caribbean and Latin America, North America and Sub Saharan Africa.

3.2.3 Regional variations

On a regional level, there are a lot of differences. The potentially available arable land is divided unevenly over the world. Especially in regions like North Africa, South Asia[10] and Japan there is very little arable land left for expansion. At this moment already 94% of the potentially available cropland is being used in South Asia. On the other hand, by the end of the twentieth century, sub-Saharan Africa and Latin America were still farming only around a fifth of their potentially suitable cropland. More than half the remaining global land balance was in just seven countries in these two regions: Angola, Argentina, Bolivia, Brazil, Colombia, Democratic Republic of Congo and the Sudan (FAO, 2002). The regional distribution of cropland in use versus total suitable land (according to FAO, 2002) is shown in Figure 12.

Figure 12 Cropland in use and total suitable land



Source: FAO, 2002.

[10] South Asia refers to India, Afghanistan, Pakistan, Nepal, Bhutan, Bangladesh, Sri Lanka, Maldives

In Table 13 an overview is given of the differences between regions in the world, regarding potentially available land, according to different studies.

Table 13 Regional differences in current arable land use and additional potential in 2020 (cropland and pastures) (Gha)

<table>
<tr><th>Study</th><th>Year</th><th>Africa</th><th>Europe</th><th>Asia/ Pacific</th><th>Latin America</th><th>North America</th><th>West Asia</th></tr>
<tr><td rowspan="2">UNEP 2007</td><td>Current</td><td>1.1</td><td>0.5</td><td>1.8</td><td>0.8</td><td>0.5</td><td>0.2</td></tr>
<tr><td>2020</td><td>0.2-0.4</td><td>0</td><td>0-0.1</td><td>0.2-0.4</td><td>0</td><td>0</td></tr>
<tr><td rowspan="2">Smeets et al. 2007</td><td>Current</td><td>1.5</td><td>0.9[11]</td><td>1.4</td><td>0.8</td><td>0.5</td><td>0.2[12]</td></tr>
<tr><td>2020</td><td>0.1-0.4</td><td>0.1-0.2</td><td>0.1-0.4</td><td>0.1-0.2</td><td>0-0.3</td><td>0</td></tr>
<tr><td></td><td></td><td>Africa</td><td colspan="2">Industrial & transition Countries</td><td>East Asia</td><td>Latin America</td><td>South Asia</td></tr>
<tr><td rowspan="2">FAO 2002</td><td>Current[13]</td><td>0.3</td><td colspan="2">0.6</td><td>0.2</td><td>0.2</td><td>0.2</td></tr>
<tr><td>Potential</td><td>0.8</td><td colspan="2">0.7</td><td>0.1</td><td>0.9</td><td>0</td></tr>
<tr><td></td><td></td><td>Africa</td><td>Europe</td><td>Asia/ Pacific</td><td>Latin America</td><td>North America</td><td>South Asia</td></tr>
<tr><td rowspan="2">Fischer, Schrattenholzer, 2000</td><td>1990</td><td>1.3</td><td>0.8</td><td>1.2</td><td>0.8</td><td>0.5</td><td>0.3</td></tr>
<tr><td>2020</td><td>0.04</td><td>0.01</td><td>0.01</td><td>0.03</td><td>0</td><td>0</td></tr>
</table>

Large differences in the total available land are mainly caused by differences in methodology. Some studies assume an interchangeability between cropland/pastures and forests and other studies make the assumption that the total arable/pasture land is fixed and land becomes available due to an increase in yield and technological advancements.

According to estimations of the FAO (2002) in 2030 about 20% of the extra food production is the result of the expansion of the arable land, 70% of increasing yields and the rest of cropping intensity. The expectation is that especially in sub-Saharan Africa and in Latin America the arable land will expand at the expense of forests. This expectation is confirmed by the findings of the GEO-4 study of UNEP. This study also shows that in regions like North America and Europe the amount of arable land will decrease and the amount of forest will increase. Overall, between 2000-2005 every year the net deforestation was about 7.3 Mha. This includes afforestation and natural expansion. 24% of the deforestation took place in Brazil (FAO, 2006). In Figure 13 an overview is given of the net change per region.

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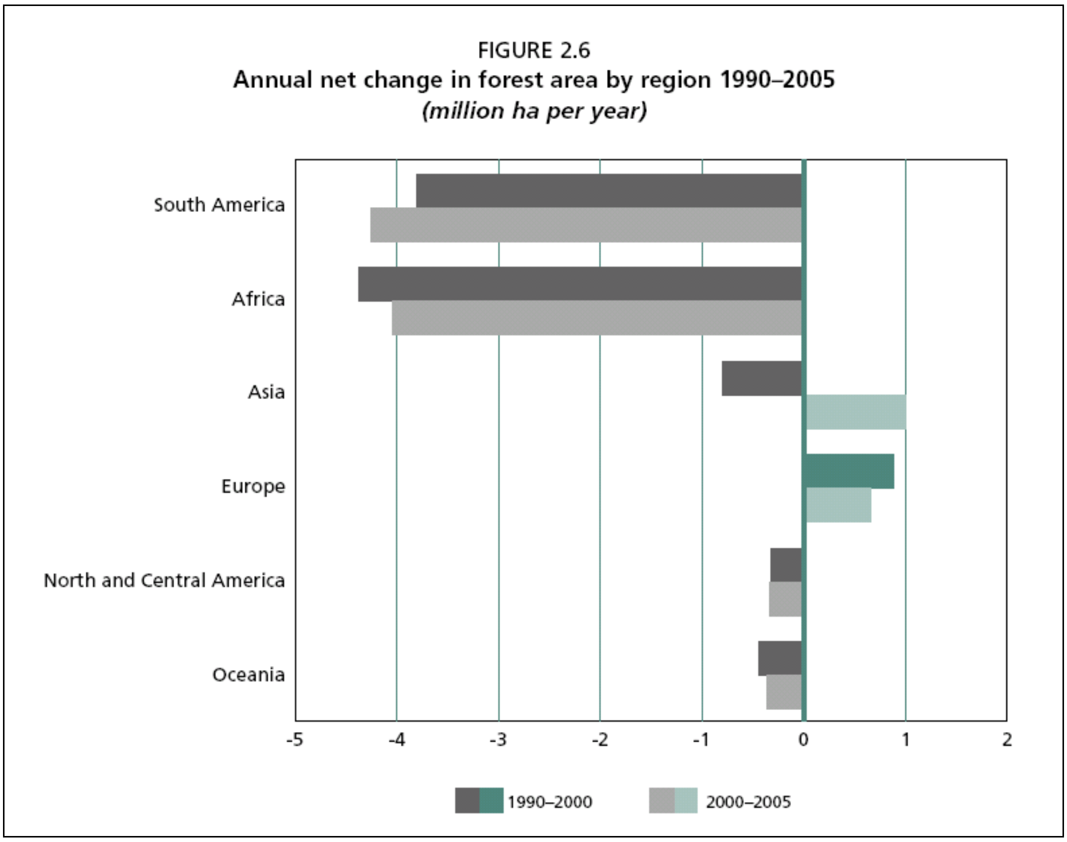
11 Overlap between Europe and Asia.

12 South Asia.

13 Only cropland.

Figure 13 The net change in forest area per region



Source: FAO, 2006.

Of course these trends are only visible in the studies that allow the interchangeability of land uses.

3.2.4 Idle land

Besides the change in land use between cropland, pastures and forest there also is a large potential of idle land. Especially in Russia, Ukraine and Kazakhstan the last 15 years almost 23 Mha of arable land became idle as a result of the breakup of the Soviet Union. Also in the United States (9 Mha) and Europe idle land increased. Here the main reasons were policy measures aimed at limiting production or ensuring more sustainable land use (FAO, 2008).

Smeets et al. (2007) have a different approach. They estimate that between 730 Mha up to 3.6 Gha of agricultural land might become available in 2050, as a result of advancement of agricultural technology for food production, representing the (technical) potential to increase the efficiency of food production. Achieving the high side of this range would require a very drastic change of global agriculture, including for example landless animal production, genetically modified organisms and implementation of the best available technologies an very high levels of irrigation. Hoogwijk et al. (2005) estimate global abandoned cropland and low-productivity land at 3 to 4 Gha in 2100.

Is should be noted, however, that idle and set aside land can have environmental benefits, i.e. converting that land into (intensive) agriculture will have a negative environmental impact. The FAO states that of the 23 Mha idle land in the former Soviet Union, 13 Mha could be returned to use with little environmental impact[14]. In (EEA, 2007), the EEA states that a number of studies have shown that increased agricultural biomass production for energy purposes could cause additional pressures on agricultural biodiversity as well as on soil, water and air resources.. Recent analysis in Germany (where agricultural bioenergy production is already well-developed) showed that potential and actual impacts on water quality and biodiversity have become real environmental concerns. This relates to the
conversion of grassland or set-aside land to arable biomass crops, potential inappropriate application of biogas digestate on farmland, higher grassland intensity for biogas production as well as indirect environmental effects via land use intensification on arable and grassland. The EEA thus concludes and recommends that that at least 3% of present intensively used farmland has be set-aside by 2030 for nature conservation purposes (EEA, 2007).

3.3 Key uncertainties

As mentioned earlier, there are significant differences between the studies analysed. Although most authors agree on the current land use pattern, the outcome of the forecasts differ a lot because of the assumptions they made.

The main reason for different outcomes is the method used by the authors. Some assume an interchangeability between different land types, while others assume a fixed area of all land types. This means that for some studies more land is used because the total area of agricultural land can increase at the expense of forests and in other studies less land is used because of an estimated surplus of agricultural land, as a result of increased yields and technological advancements.

General uncertainties
Although most studies agree on the current land use, there still is a considerable uncertainty in the datasets used in the studies. Almost every study uses a model based on geographical grids. Errors will occur because of the size of the grids or allocation methods. More detailed studies are required to improve the reliability of the dataset (FAO is, in fact, currently updating their analysis, using a finer grid).

In some studies different scenarios are used. These give a useful insight in possible futures, but they are also the source of many different outcomes of the estimated land use change. These scenarios often incorporate different assumptions regarding population growth, per capita consumption, technological advancements, geographic optimization of production and wood demand.

[14] http://www.fao.org/newsroom/en/news/2008/1000808/index.html.

Demand uncertainties
For estimating the available land it is of course necessary to estimate the demand of different products from the land: food, feed, wood. These demands depend largely on the size and growth of the population, the diet of the population, economical and political (e.g. agricultural and trade policy) developments and the wood demand.

Technical uncertainties
The FAO (2002) estimates that 70% of the increase in production growth is a result of yield improvements. This means that a small difference in assumption can make a large difference in the outcome of available land. In a lesser way, this also applies to technological advancements.

Economical uncertainties
The demand for food and feed also depends on the food prices and people's purchasing power and GDP. The effective demand of food can be higher than the real need of food, because wealthy consumers may indulge to excess, while the very poor may not be able to afford even basic foods.
Assumptions on globalization and a world market for food, feed and biomass also influences the outcome of the forecasts.

Geographical uncertainties
Finally, the uncertainties regarding the geographical assumptions like water availability, land degradation and climate change account for many uncertainties, especially in the regional context.

3.4 Conclusions

Land availability is not a given, but depends strongly on developments in demand, crop prizes, agricultural developments, environmental demands, etc. Both agricultural and forest land area can be increased or reduced in the future (at least on a global scale), depending on these factors. Any change in land use, however, will have an environmental (and often also a social) impact.

Although the outcomes of the studies differ significantly, the overall conclusion can be that there will be sufficient land available for the production of food, feed and wood to comply with the rising demand in the coming decades. Either because of the expansion of the total agricultural land or becoming available of surplus land. A very important remark must be added that this conclusion can only be drawn on a global scale. When looking at regional developments, several bottlenecks can be identified.

First of all, the land availability is distributed very unevenly. Regions like North Africa an South Asia are already using more than 90% of the available land, so there is very little room for expansion. Secondly, the availability of water for irrigation is just as uneven distributed as available agricultural land. Although irrigation potential is difficult to estimate accurately. A rough indication shows there is more then enough irrigation potential, but also in this case, regions like East and South Asia and North Africa will encounter many problems.

4 Recommendations

Additional agricultural land is expected to be required for food and feed production in the next decade. Increasing biofuels demand will come on top of these developments, further increasing land demand. A significant part of the increase in demand for agricultural products is expected to be met by agricultural intensification, another part could be met by putting idle or marginal land into use. However, forecasts still show that the amount of agricultural land used as cropland and pastures will also increase further, for example at the expense of forest areas. Policies can thus reduce land use change, for example by:

- Promoting the use of crops with high yields or, in case of biofuels and bioenergy, by promoting the use of previously unused forest or agricultural waste.
- Promoting technological development in agriculture, aimed at increasing the yields of crop and livestock production.
- Promoting the use of idle or marginal land.
- Etc.

More insight into yields and future yield estimates for the most relevant crops and regions, and monitoring of the developments in this area might be required for this. In view of the uncertainties in the prediction of future developments in agricultural and forest land areas, accurate monitoring of these is also to be recommended.

Achieving yield improvements by good agricultural practices and agricultural intensification is crucial to limiting the demand for agricultural land. However, one has to weight the environmental benefits from this reduced land use against the environmental impact of agricultural intensification, since this can also have a negative impact on biodiversity, emissions, etc. The same can be said about idle and set aside land: part of it can be converted to agricultural use without significantly harming the environment, but part of it can not. Local and regional assessments can provide more insight into these impacts.

As the biofuel scenarios show, the global biofuels production increase that is expected for the next decade will have a very profound effect on the market of a number of commodities also used as food or feed. As this is likely to affect prices, these effects should be considered prior to setting biofuel policies. Care should be taken to reducing these effects, for example by allowing agricultural markets to adjust, and agricultural production to increase sufficiently over time.

This study focussed on global data and studies, but there are large regional differences in land and feedstock demand and availability. Regional impacts of policies will thus vary significantly. We recommend to analyse these further, and take these into account when assessing the impact of biofuels policy in more detail.

The estimate of the biofuels feedstock and land use demand in 2020 could be improved further by improving

- The yield estimates, e.g. with an more detailed analysis of where the feedstock will be grown.
- The feedstock analysis, e.g., with more detailed modelling of how the global biofuel targets will be met:
  - Where would the feedstock be expected to be cultivated.
  - What will be the impact of biofuels policies on price developments of the various commodities.
  - What market dynamics (such as demand shift between commodities) might be expected.
  - What impact could yield developments have on the feedstock mix.
  - What would be the constraints on feedstock for 2nd generation biofuels, and what would be the impact of their large scale use for biofuels.
  - What impact would sustainability certification have on the biofuel feedstock mix.
  - How could the biofuels targets be met without endangering food security.
  - Etc.

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Agricultural land availability and demand in 2020

A global analysis of drivers and demand for feedstock, and agricultural land availability

Annexes

Report

Delft, June 2008

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A Literature overview - Drivers and demand for land and feedstock

In the following, an overview is provided of results and methodology used in the literature included in the literature analysis of chapter 2.

Table 14 Results and methodology used in the literature included in the literature analysis of chapter 2

Source	Drivers	Outlook drivers year of study	Outlook drivers 2020	Outlook landuse year of study	Outlook landuse 2020	Remarks
OECD-FAO, 2007 Agricultural outlook 2007-2016	✓ Population ✓ Economics ✓ Food ✓ Meat ✓ Biofuel × Bioenergy × Wood × Pulp × Paper × Textiles × Petrochemical industry	**2016** Energy crops and biofuel use: US 110 Mton maize, 46 Gl EtOH EU 5 Mton maize, 17.5 Mton wheat, 15 Gl EtOH, 14 Gl diesel Canada 1.55 Mton wheat, 3.75 ton Maize 2.0 Gl EtOH, 0,7 Gl biodiesel China 7.7 Mton maize, 4.6 Gl EtOH Brazil 44 Gl EtOH, 495 Mton sugar cane Wheat production: 672.6 Mton Coarse grains production: 1,184.3 Mton Rice production: 469.0 Mton Oilseed meals production: 238.6 Mton Vegetable oil production: 134.6 Mton of which palm oil 54.1 Mton Meat production: 95.7 kg rwt/capita	**2020** The trend from 2012 to 2016 is used to estimate values for 2020 Energy crops and biofuel use: US 116 Mton maize, 48 Gl EtOH EU 5.5 Mton maize, 23 Mton wheat, 19 Gl EtOH, 18 Gl diesel Canada 1,6 Mton wheat, 3.9 ton Maize 2.1 Gl EtOH, 0.7 Gl biodiesel China 9.6 Mton maize, 5.8 Gl EtOH Brazil 55 Gl EtOH, 610 Mton sugar cane Wheat production: 690 Mton Coarse grains production: 1,713 Mton Rice production: 487 Mton Oilseed meals production: 255 Mton Vegetable oil production: 147 Mton of which palm oil 61Mton Meat production: 98.1 kg rwt/capita			This report presents an outlook for 2016. Values are presented per region as well as for the whole world. Quantitative information is presented in the annexes. Rwt=retailweight

Source	Drivers	Outlook drivers year of study	Outlook drivers 2020	Outlook landuse year of study	Outlook landuse 2020	Remarks
UNEP GEO-4, 2007	✓ Population ✓ Economics ✓ Food ✓ Meat ✓ Biofuel ✓ Bioenergy × Wood × Pulp × Paper × Textiles × Petrochemical industry	**2020** Traditional biofuel prod: Africa 16-17.5 EJ Asia/Pacific 32-35 EJ Europe 2 EJ Latin America/Caribbean 3-4 EJ North America 2-3 EJ West Asia: 0 EJ World: 55-61.5 EJ Energy use: 525-625 EJ	**2020** Forecasts already for 2020	**2020** Cropland + Pasture: Ca. 5.2-5.7 Gha Percentage of total land cover for biofuels: ~8% (Given per region see Fig. 1-18) Forest land: Ca. 4.0-4.2 Gha	**2020** Forecasts already for 2020	There are 4 scenario's which give a range of outcomes. All parameters are given per region. This reports presents also outlooks for cereal yields and food availability. Forest land and cropland/pastures predictions are modeled with image. Future land use is modeled using IMAGE
FAO Global Forest Resources Assessment 2005	× Population × Economics × Food × Meat × Biofuel × Bioenergy ✓ Wood ✓ Pulp ✓ Paper × Textiles × Petrochemical industry	**2000-2005** Increase in planted forests: $2.8 \cdot 10^6$ ha/year from $140 \cdot 10^6$ ha in 2000 (87% of this growth is from productive forests, the rest are protective forest plantations)	-			This report describes trends from 2000-2005. Increases of area for productive forests are presented per region in Table 5-4

Source	Drivers	Outlook drivers year of study	Outlook drivers 2020	Outlook landuse year of study	Outlook landuse 2020	Remarks
CE, 2007 Biofuels and their global influence on land availability for agriculture and nature	✓ Population ✓ Economics ✓ Food ✓ Meat ✓ Biofuel ✓ Bioenergy × Wood × Pulp × Paper × Textiles × Petrochemical industry	**<u>2020</u>** <u>Population:</u> 7.5 billion <u>Economic growth:</u> GDP increases with 225% compared to 2007 (based on $54,312 billion in 2007 from WEO, this is $122,201 billion in 2020) <u>Meat consumption:</u> Increases 35% compared to 2005 <u>Dairy consumption:</u> Increases 23% compared to 2005 <u>Cereals consumption:</u> Increases 23% compared to 2005 <u>Oil and oilseed meals consumption:</u> Increases 44% compared to 2005 <u>Sugar consumption:</u> Increases 32% compared to 2005 <u>Energy demand:</u> Increases from 417 in 2005 to 603 EJ/y in 2020. The percentage biomass and other renewables remains more or less the same.	**<u>2020</u>** Forecasts already for 2020			This study presents the main drivers for landuse. Figures are based on other studies. This study also gives forecasts for land use in 2020. Food consumption is estimated from Figure 6

Source	Drivers	Outlook drivers year of study	Outlook drivers 2020	Outlook landuse year of study	Outlook landuse 2020	Remarks
MNP UNEP 2006, Crossroads to planet earth	✓ Population ✓ Economics ✓ Food ✓ Meat ✓ Biofuel ✓ Bioenergy ✗ Wood ✗ Pulp ✗ Paper ✗ Textiles ✓ Petrochemical industry	**2050** Population: 6,1 billion in 2000 to 9 billion in 2050 Economics: Income grows from $5,300 in 2000 to $16, 000 in 2050 Energy consumption: From 400 EJ in 2000 to 900 EJ in 2050	**2020** Population: 7.8 billion (non linear) Economics: $9, 600 GDP/capita $ 74,880 GDP Energy consumption: 600 EJ			Worldwide biodiversity outlook for 2050 given 4 different scenario´s.
Hoogwijk et al., 2003 Exploration of the ranges of the global potential of biomass for energy	✓ Population ✓ Economics ✓ Food ✓ Meat ✗ Biofuel ✗ Bioenergy ✓ Wood ✓ Pulp ✗ Paper ✓ Textiles ✓ Petrochemical industry	**2050** Food demand: From 9.4 MJ/day ($5.0*10^{12}$ kg grain eq/day) in 2003 to 10.1 MJ/day ($8.2*10^{12}$ kg grain eq/day) in 2050 Meat demand: 0.22 grain eq/kg/day Dairy demand: 1.23 grain eq/kg/day Plant demand: 0.90 grain eq/kg/day Wood demand: From 350 in 2003 to 1,756 Mton/yr in 2050 Pulp demand: From 175 in 2003 to 307 Mton/yr in 2050 Petrochemicals: From 200 in 2003 to 398 Mton/yr in 2050 Iron production: From 550 in 2003 to 1,274 Mton/yr in 2050 Cotton demand: From 20 in 2003 to 142 Mton/yr in 2050 Rubber demand: From 7 in 2003 to 31 Mton/yr in 2050	**2020** Food demand: 9.7 MJ/day, $6.2*10^{12}$ kg grain eq/day Meat demand: 0.21 grain eq/kg/day Dairy demand: 1.20 grain eq/kg/day Plant demand: 0.88 grain eq/kg/day Wood demand: 859 Mton/yr Pulp demand: 223 Mton/yr Petrochemicals: 272 Mton/yr Iron production: 812 Mton/yr Cotton demand: 64 Mton/yr Rubber demand: 16 Mton/yr	**2050** Agricultural land for food: 2.4-3.1 average scenario 2.6 Gha Wood demand: 351 Mha Petrochemicals: 5-100 Mha Pulp: 51 Mha Iron industry: 9-89 Mha Cotton: 71 Mha Rubber: 15 Mha	**2020** Agricultural land for food: 2.5 Gha Wood demand: 211 Mha Petrochemicals: 3-68 Mha Pulp: 38 Mha Iron industry: 3-57 Mha Cotton: 32 Mha Rubber: 8 Mha	In this study the potential for bio energy is calculated. They quantify the landuse for several drivers and from there they estimate the surplus land for biomass production for energy. For food demand there are 3 scenarios: vegetarian, moderate and affluent. Figures presented here are from the moderate scenario. Amounts of food are expressed in grain equivalents, reason for this is to make all scenarios comparable. The potential for bio-energy is 33-1130 EJ/yr, the range is caused by a range of assumptions. See Table 9 in the article. It is assumed that actual food production is twice the demand of food, to ensure food security, allowing for production variations between years, and transport and distribution losses.

Source	Drivers	Outlook drivers year of study	Outlook drivers 2020	Outlook landuse year of study	Outlook landuse 2020	Remarks
Smeets et al., 2007 A bottom up assessment and review of global bio-energy potentials to 2050	✓ Population ✓ Economics ✓ Food ✓ Meat × Biofuel × Bioenergy ✓ Wood × Pulp × Paper × Textiles × Petrochemical industry	**2050** Population: 8.8 billion Food demand: From 2,739 in 1998 to 3,302 kcal/cap/day in 2050 Industrial roundwood demand: From 1.5 in 1998 to 1.9-3.1 Gm^3 (22-36 EJ) in 2050 Woodfuel demand: From 1,7 in 1998 to 1.7-2.6 Gm^3 (20-30 EJ) in 2050 Energy demand: From 418 in 2001 to 601-1,041 EJ/yr in 2050	**2020** Food demand: 2,977 kcal/cap/day Industrial roundwood demand: 1.9 Gm^3 (22 EJ) Woodfuel demand: 1.9 Gm^3 (22 EJ) Energy demand: 574 EJ/yr	**2050** Forest plantations: From 123 in 1995 to 124-292 Mha (191 in medium scenario) plantations for industrial roundwood and woodfuel. Cropland: From 1,5 in 2002 to 1.6 Gha in 2030, 1.6-1.7 Gha in 2050 (different sources) 1.3-4.2 Gha (this study) The area is given per region (see table 11) Pastures: From 3,5 in 2002 to 3.6 Gha in 2030 or 3.5-3.8 Gha in 2050 (different sources)	**2020** Forest plantations: 154 Mha Cropland: 1,4-2,5 Gha Pastures: 3.5-3.6 Gha	Given 4 scenario´s this study determines the potential for bio-energy crops using the Quickscan model. They identify the drivers for landuse, determine the demand for agricultural products and land availability. Surplus land can be used for energy crops. The scenario´s differ mainly in the efficiency of food production. Climate change is not included.
Fischer and Schrattenholzer 2001, Global bioenergy potentials through 2050	✓ Population ✓ Economics ✓ Food ✓ Meat × Biofuel × Bioenergy ✓ Wood × Pulp × Paper × Textiles ✓ Petrochemical industry	**2050** Population: 5.3 in 1990 to 10 billion in 2050	**2020** Population: 7.65 billion	**2050** Forests: From 3.68 Gha in 1990 to 3.87 Gha in 2050 Grassland: From 3.38 Gha in 1990 to 3.30 Gha in 2050 Arable land: From 1.52 Gha in 1990 to 1.74 Gha in 2050	**2020** Forests: 3.78 Gha Grassland: 3.34 Gha Arable land: 1.63 Gha	This study estimates the potential bioenergy in 2050. They obtain 280-320 EJ/yr in 2020. This is partly obtained by energy crops and wood. Results are given per region.

Source	**Drivers**	**Outlook drivers year of study**	**Outlook drivers 2020**	**Outlook landuse year of study**	**Outlook landuse 2020**	**Remarks**
Rosegrant et al., 2000, 2020 global food outlook	× Population × Economics × Food ✓ Meat × Biofuel × Bioenergy × Wood × Pulp × Paper × Textiles × Petrochemical industry	**<u>2020</u>** <u>Meat demand:</u> 327 Mton (213 developing countries, 114 developed countries)	**<u>2020</u>** Forecasts already for 2020			To obtain outlooks for the meat demand they used the ISPRI model.
Smeets and Faaij 2007, Bioenergy potentials from forestry in 2050	× Population × Economics × Food × Meat × Biofuel × Bioenergy ✓ Wood × Pulp × Paper × Textiles × Petrochemical industry			**<u>2050</u>** <u>Forest plantations</u>: 103-234 Mha from 103 Mha in 1995. These are only industrial forest plantations, non industrial plantations (for recreation etc.) are not taken into account.	**<u>2020</u>** <u>Forest plantations</u>: 103-163 Mha	This study presents outlooks for round wood and fuel wood demand as well as for the area of forest plantations. Values are estimated on basis of extensive literature research. Practical information: density of wood: 0,58 ovendry tm^{-3}, HHV 20 GJ (oven dry ton)$^{-}$
FAO 2002, World agriculture towards 2015/2030	✓ Population ✓ Economics ✓ Food ✓ Meat × Biofuel × Bioenergy ✓ Wood ✓ Pulp ✓ Paper × Textiles × Petrochemical industry					

B Literature overview – Global agricultural land availability

In the following, an overview is provided of results and methodology used in the literature included in the literature analysis of chapter 3.

Table 15 Results and methodology used in the literature included in the literature analysis of chapter 3

Source	**Coverage**	**Subdivision of land use**	**Total potential**	**Remarks, uncertainties and assumptions**
UNEP, 2007 Global Environmental Outlook (GEO-4)	World and regions	× Total agricultural × Total arable land ✓ Cropland ✓ Pasture ✓ Forest	**2000** • Cropland and pasture: 4,920 Mha • Forest: 4,700 Mha **2025** • Cropland and pasture: 5,360-5,910 Mha • Forest: 4,130-4,360 Mha **2050** • Cropland and pasture: 5,610-6,570 Mha • Forest: 3,770-4,350 Mha	GEO-4 uses 4 demand driven scenarios: Markets First, Policy First, Security First and Sustainability First. These scenarios are derived from the IMAGE model. All scenarios show a clear trend of a decrease in forest area and an increase of cropland and pasture.
FAO, 2002 World Agriculture: towards 2015/2030	World and regions	✓ Total agricultural ✓ Total arable land ✓ Cropland ✓ Pasture ✓ Forest	**2000** • Arable and permanent crops: 1,500 Mha • Permanent pastures: 3,460 Mha • Forest: 3,870 Mha **2030** • Additional maximum potential: 2,800 Mha, of which: – Forest: 1,260 Mha – Protected area: 340 Mha – Built-on: 80 Mha	A comparison of soils, terrains and climates with the needs of major crops suggests that an extra 2.8 Gha are suitable in varying degrees for the rainfed production of arable and permanent crops. Only a fraction of this extra land is realistically available for agricultural expansion in the foreseeable future, as much is needed to preserve forest cover and to support infrastructural development. There will be no overall shortage of land or water for irrigation, but serious problems will persist in some countries and regions.
Smeets et al., 2007 A bottom-up assessment and review of global bio-energy potentials to 2050	World and regions	✓ Total agricultural ✓ Total arable land ✓ Cropland ✓ Pasture ✓ Forest	**2050** • Surplus agricultural land: 729-3,585 Mha, of which 450-2,100 Mha available for bioenergy (low grade land)	Estimation of the surplus agricultural land in 2050 due to reducing the area of land needed for food production by increasing the efficiency of food production. The total area of agricultural land remains more or less the same. The availability in different regions of the world will be insufficient to provide the demanded amount of food, especially Japan, South-East Asia and North Africa.

Source	Coverage	Subdivision of land use	Total potential	Remarks, uncertainties and assumptions
CE Delft, 2007 Biofuels and their influence on agriculture and the food market	World	✓ Total agricultural ✓ Total arable land ✓ Cropland ✓ Pasture ✓ Forest	**<u>Current</u>** • Arable and permanent crops: 1,500 Mha • Pastures and grass: 3,500 Mha • Forest: 3,900 Mha **<u>2020</u>** • Arable and permanent crops: 1,700 Mha • Pastures and grass: 3,500 Mha • Forest: 3,700 Mha	Calculation of the conversion of forests to arable and permanent crop land. Based on current trends and projections on deforestation, expansion of arable land and degradation of agricultural land. Not taken into account in the calculation but mentioned, the likely negative effects of climate change on agricultural production.
MNP, 2007 Cross-Roads of Life on Earth	World	✓ Total agricultural × Total arable land × Cropland × Pasture × Forest	**<u>2020</u>** • Total crop area: 5,000-5,600 Mha	Estimation of the total crop area required to meet world demand, based on four scenarios using the IMAGE model. This is probably the sum of arable land and pastures.
Hoogwijk et al., 2005 Potential of biomass energy out to 2100, for four PICC SRES land-use scenarios	World	× Total agricultural × Total arable land ✓ Cropland × Pasture ✓ Forest	**<u>1970</u>** • Abandoned cropland: 0 Mha • Low-productivity: 4,000 Mha • Restland: 2,400 Mha • Cropland: 3,000 Mha • Forest: 3,000 Mha • Bioreserve: 1,000 Mha **<u>2020</u>** • Abandoned cropland: 300-700 Mha • Low-productivity: 2,800-3,100 Mha • Restland: 2,200-2,500 Mha • Cropland: 3,000-3,800 Mha • Forest: 3,100-3,300 Mha • Bioreserve: 700-800 Mha	Land use patterns of four scenarios based on the IMAGE 2.2 model. For 2020 the scenarios show a strong decrease in the low-productivity land, especially on the long term (2100) the amount of low-productive land decreases due to the increase in productivity as a result of technological improvements and positive climate change feedbacks. All scenarios show a decrease of agricultural land, either because of a surplus or because of a decreased suitability. This means an increase of available land for biomass/biofuels.
Hoogwijk et al., 2003 Exploration of the ranges of the global potential of biomass for energy	World	× Total agricultural × Total arable land ✓ Cropland ✓ Pasture ✓ Forest	**<u>Current</u>** • Land for food/feed crops: 1,500 Mha • Pasture land: 3,500 Mha • Forest: 4,000 Mha • Other land: 4,200 Mha **<u>2050</u>** • Surplus agricultural land: 0-3,700 Mha • Degraded land: 430-580 Mha	Study on the availability of biomass. Six biomass resource categories for energy are identi9ed: energy crops on surplus cropland, energy crops on degraded land, agricultural residues, forest residues, animal manure and organic wastes. Surplus of agricultural land is assessed based on the potentials of food production on a global level, restricted by the current use of land for food production (5 Gha). Degraded land is assessed by an analysis of selected studies.

Source	Coverage	Subdivision of land use	Total potential	Remarks, uncertainties and assumptions
Fischer and Schrattenholzer, 2001 Global bioenergy potentials through 2050	World and regions	× Total agricultural × Total arable land ✓ Cropland ✓ Pasture ✓ Forest	**<u>1990</u>** • Arable: 1,520 Mha • Forest: 3,980 Mha • Grassland: 3,380 Mha • Other: 4,200 Mha **<u>2050</u>** • Arable: 1,740 Mha • Forest: 3,870 Mha • Grassland: 3,300 Mha • Other: 4,200 Mha	Estimation of land use change based on the IIASA's BLS-BAU scenario. There is an increase of arable land at the expense of forest and grassland