Challenges and opportunities for future production of food, feed and biofuel - A land use perspective

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A land use perspective

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Abstract

The world is facing of a number of great challenges as the population is growing and living habits are getting more resource demanding. At the same time as food security has to be assured, growth in biofuel and meat production pose a risk for increasing land use conflicts and negative environmental consequences.

In this report production of food, feed and biofuels are discussed from a land use perspective. The report provides an overview of available knowledge and critical issues regarding current and future land use in a global perspective. The aims of the report are to identify key issues related to land use and areas in need of further research. In addition the possibility to secure global demand for food in a sustainable way, at the same time as parts of global agriculture areas are used for production of biofuels, is evaluated and discussed.

The report suggests that a limited production of first generation biofuels is a viable option in the short/medium term, until second generation biofuels and other technologies become available on the market. Redistribution of agriculture land, development of new and sustainable farming techniques, dietary change and reduction of food losses and waste are identified as available options to reduce future land use pressure. To avoid increasing land use conflicts there is a need for further research, particularly in areas outlined in this report. However it is also emphasised that substantial knowledge of ways to reduce land use conflicts is available, and should be implemented into the society today.

Keywords

Land use, food, feed, biofuel

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Preface

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The authors

Contents

1. INTRODUCTION

The world is facing of a number of great challenges as the population is growing and living habits are getting more resource demanding. At the same time as food security has to be assured, biofuel and meat production is increasing. The use of biomass resources is also expected to increase in the chemical industry for the production of fine and bulk chemicals. In this report the challenges and opportunities for future production of food, feed and biofuels (including bulk chemicals) are discussed from a land use perspective. The objective of the report is to describe the current use of land in a global perspective (chapter 2), present key challenges that may drive future land use change (chapter 3), describe predictions of future land use change (chapter 4) and discuss opportunities for minimizing land use conflicts (chapter 5). In the end of each chapter follows a summary of previous discussed content.

The report provides an overview of available knowledge, research status and critical issues regarding current and future land use. Based on current and future challenges and opportunities, the report is aiming at identifying key issues related to land use and areas in need of further research. A more specific aim of this report is to answer the question whether it is possible to secure global demand for food in a sustainable way, at the same time as parts of global agriculture areas are used for production of biofuels. The report is purposed for the general public as well as for organizations, researchers and politicians interested in sustainable management of natural resources and land.

2. PRESENT LAND USE

To understand and discuss questions related to land use change it is essential to have an idea of how global land resources is currently used and distributed. In chapter 2 present land use and the dynamics between forest, agriculture land and urban areas will be described (2.1) and be followed by a discussion on reliability of land use data (2.2). Thereafter the focus will be narrowed down to look more specifically at the distribution of agriculture land for production of food, feed and biofuel (2.3).

2.1 Land use and the dynamics between forest, agriculture land and urban areas

About two thirds of the global surface is covered by oceans and the remaining third by land. The global land areas make up approximately 13.4 billion hectares (FAO, 2006a). In Table 1 the global land use distribution in year 2000 is declared for, based on data adapted from FAO. Forest and agriculture land roughly cover two thirds of the global land area (30 %, 37 %) and remaining land is distributed between urban areas (< 1 %) and other land (31 %) (FAO, 2006a). During the last centuries the overall trend in global land use change has been increasing agriculture areas and urban areas at expense of a decreasing forest cover and land with other vegetation. Figure 1 shows the global land use change for forest, pasture and arable land between 1700 and 2000, based on historical data from Goldeweijk (2001), Ramankutty et al. (2006) and FAO data for year 2000 (FAO, 2006a). During this period, data indicate a 25 % decrease in global forest cover and a six fold increase of crop-land and permanent pasture areas. As will be discussed in section 2.2 knowledge of global land use is still limited why variations in land use data appear in the literature. In the following sections the dynamics in land covered by forest, agriculture land and urban areas will be described, primarily based on estimates from FAO.

Table 1. Global land use distribution in 2000

Category	Area (Mha)	Extent (%)
Forest	3989	30
Permanent pasture	3442	26
Arable and permanent crops	1534	11
Urban areas*	40	< 1
Other land**	4414	31
Total	13419	100

*Includes cities with more than 100 000 inhabitants. ** Includes all land not included in above categories such as deserts, polar areas, unvegetated and unhabited land, wetlands and inland water. Source: (FAO, 2006a).

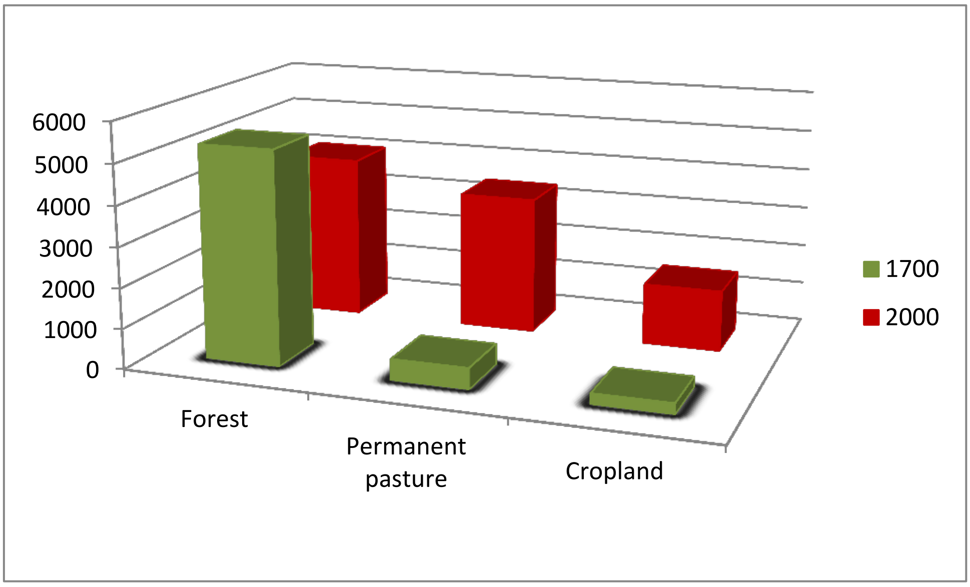


Figure 1. Land use change in million hectares between 1700 and 2000
Sources: Pasture and cropland areas in 1700; (Goldewijk, 2001) forest area in 1700; (Ramankutty et al., 2006), data for 2000; FAOSTAT 2010.

2.1.1 Forest

The Global Forest Resource Assessment (FRA) (FAO, 2010a), which is published every fifth year, is regarded as the most comprehensive assessment of forest and forestry to date and is the main source of forest area data in FAOSTAT. The following summary of current status and trends of the world forest area is extracted from the latest edition of FRA from 2010.

The global forest areas cover approximately 4 billion hectares of the land surface. Primary forests, natural regenerated forests and planted forest account for 36 %, 57 % and 7 % respectively. About half of the global forest area is situated within the borders of the Russian Federation, Brazil, Canada, the United States of America and China. The majority of the remaining primary forest is found in the Amazon in South America (46 %). Table 2 shows the geographical distribution of global forest areas (FAO, 2010a).

During the last three centuries the total loss of forest has been estimated to be in the range of 700-1100 million hectares (Foley et al., 2005). The global annual net loss of forest in the last decade has been 5.2 million hectares, an area comparable to the size of Costa Rica. Although the global deforestation rate still is alarmingly high, a decline in loss of forest has been noted compared to in the 1990s when the corresponding rate was 23 % higher than today. Also in South America, where the greatest losses of forest occur, the annual net loss has decreased from 4.4 million hectares during the period between 2000 and 2005 to 3.6 million hectares between 2005 and 2010. Deforestation today mainly occurs in South America, Africa and South East Asia but also Oceania had substantial losses of forest due to severe drought and forest fires during the last decade. In Figure 2 the change in forest areas is shown for the countries with highest net loss and gain between 2005 and 2010 (FAO, 2010a).

In other parts of the world the forest cover is increasing due to afforestation and natural expansion of existing forests. North America and Europe are two vast regions where the net change in forest has been positive for more than two decades. Also in Asia, where the forest cover was decreasing in the 1990s, an average net gain of approximately 2.2 million hectares of forest was noted between 2000 and 2010. The net gain of forest in Asia over the last decade is primarily a result of large-scale afforestation in China. Between 2005 and 2010 the area of planted forest increased with 5 million hectares per year and today planted forest accounts for 264 million hectares or 7 % of the global forest cover. The area of protected forest, such as forest in natural parks and reserves, is also increasing and is currently estimated to represent 12.5 % of the global forest areas (FAO, 2010a).

The primary cause of deforestation is conversion of forestland to agriculture areas (FAO, 2010a), although timber extraction and exploitation of firewood and forest products also have been contributing factors (Ramankutty et al., 2006). In an FAO study (2006a) it was estimated that during year 2000, approximately three quarters of lost global forest areas were converted to crop-land, about 20 % to permanent pasture and a smaller share to urban areas. Afforestation in 2000 mainly took place on old agriculture areas.

Table 2. Distribution of global forests

Region	Area (Mha)	% of total forest area
Africa	674	17
Asia	592	15
Europe	1005	25
North- and Central America	705	17
South America	864	21
Oceania	191	5

Source: (FAO, 2010a)

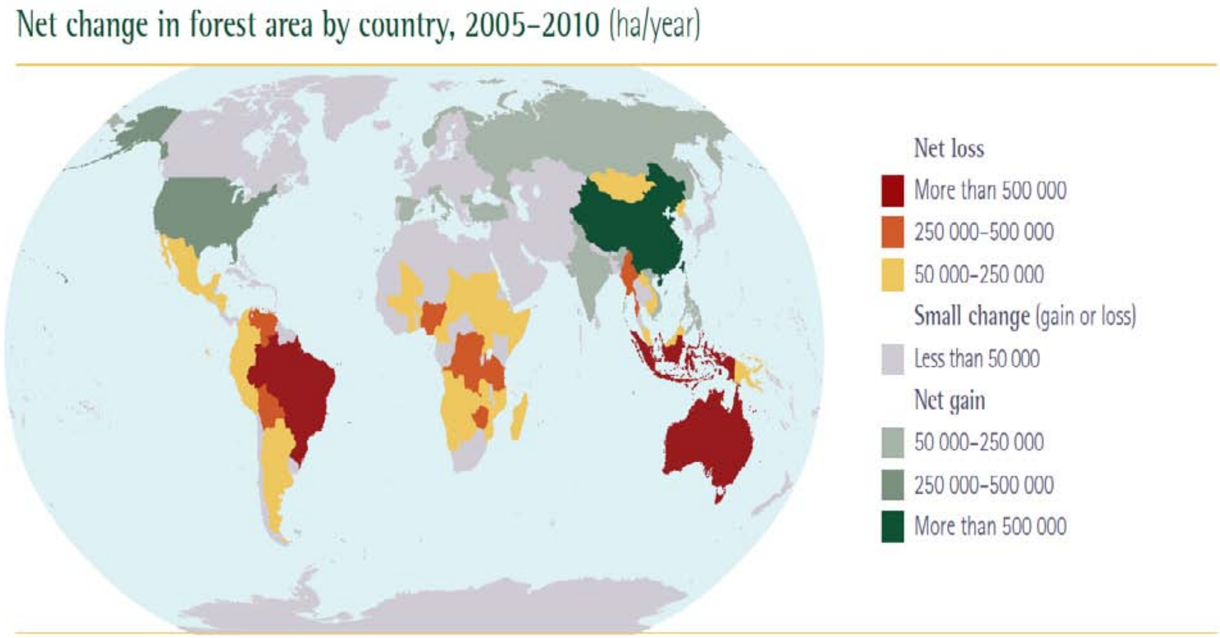


Figure 2. Net change in forest area by country, 2005-2010.
Source: (FAO, 2010a)

2.1.2 Agriculture land

In this section current status and trends of global agriculture land is described primarily based on latest available data from FAO. In the literature, the terminology used for describing different types of land use varies. In the following, FAO land use definitions (Box 1) will be used as far as possible.

Box 1. Land use definitions

Agriculture land = Arable land, permanent crops and permanent pasture.

Arable land = Land under temporary crops (double-cropped areas counted once only), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporary fallow (less than five years).

Harvested area = Total area under harvested land. Areas under double cropping are counted twice.

Permanent crops = Land cultivated with crops that occupy the land for long periods, such as cocoa, coffee and rubber, but excludes land under trees grown for wood and timber.

Permanent pasture = Land used permanently (five years and more) for herbaceous forage crops, either cultivated or growing wild.

Source: (FAO, www.fao.org)

In 2008 agriculture land covered a bit over a third of the global land area (4884 million hectares). Thirty-one percent of global agriculture land is used for cropping (arable land and permanent crops) and remaining 69 % is covered by permanent meadows and pastures (data for 2008) (FAOSTAT 2010). The largest areas of croplands are found in South Asia, Europe, South east Asia and in the United States of America (east of the Mississippi), whereas the largest proportion of pastures are situated in South America, Pacific developed countries, China, Central America, United States of America (west of the Mississippi) and in tropical Africa (Figure 3) (Ramankutty et al., 2008).

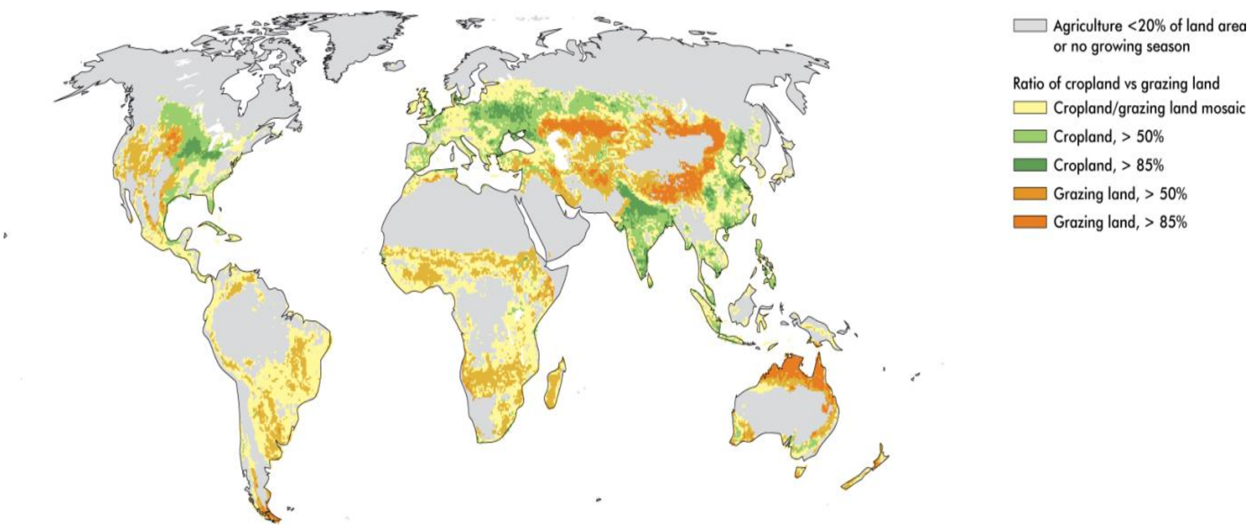


Figure 3. Distribution of croplands and pasture land in 2007
Source: (UNEP/GRID Arendal Maps and Graphics Library, 2007)

Despite the past revolution in agriculture, including intensification and highly increased yields, global agriculture areas have increased historically. Between 1966 and 1996 the annual net gain of global agriculture land was 0.3 % and during this period agriculture areas expanded from 4.6 to 4.9 billion hectares. In the beginning of this period expansion of crop-land (arable land and land under permanent crops) was dominating, the increase however slowed down in the end of the 1980s whereas permanent pasture continued to increase at the same rate as previously (Table 3) (Wood et al., 2000). FAO data for the period 1996-2006 indicate that the increase of global agriculture areas has levelled off during the last decade (FAO, 2009c), this finding is in agreement with FAOs projections of a slowdown in expansion of arable land as a result of increasing yields (Bruinsma, 2009) and the current trend of an intensified livestock production resulting in a change from extensive grazing towards mixed farming systems (Steinfeld et al., 2006).

Table 3. Trends in global agriculture land use, annual growth rates (% per year) 1966-1997

	1966-76	1976-86	1986-96
Total agriculture land	0.27	0.35	0.26
Cropland	0.33	0.49	0.18
Permanent pasture	0.24	0.28	0.28

Source: IFPRI calculations based on FAOSTAT 1999. Adapted from (Wood et al., 2000)

Regional trends however show a more dynamic picture of the distribution and dynamics of global agriculture areas. Between 1961/63 and 2005 the global arable area expanded by 187 million hectares, during this period arable land increased with 227 million hectares in the developing countries at the same time as a decline of 40 million hectares took place in the developed countries (Bruinsma, 2009). The regions where expansion of arable land was most pronounced during the last decades were South East Asia, Latin America and parts of Africa (FAO, 2009b). In most developed countries instead a stagnating trend of arable land has been noted since the late 1960s, resulting in an overall decline of arable land in the developed world since the mid-1980s (Bruinsma, 2009). Western Europe and the United States of America has experienced a decline in agriculture areas for approximately 50 years (Wood et al., 2000), other regions where land is taken out of agricultural production are Oceania and Eastern Europe (FAO, 2009b). Table 4 and Table 5 show the changes in arable land and permanent pasture between 1961 and 2007 for different regions.

Expansion of arable land has mostly increased at expense of forest while grazing areas above all has replaced natural grassland (Goldewijk and Ramankutty, 2004). There are however exceptions to this trend such as the North American prairies which were lost to croplands and big parts of the Latin American forests that have been cleared for ranching (Ramankutty et al., 2006). Former agriculture land is mainly taking out of production in favour of afforestation, urbanization or as a consequence of land degradation (FAO, 2006a).

Table 4. Arable land by region 1961, 1991 and 2007

Region	Arable land			
		Area (Mha)		Share of global arable land (%)
	1961	1991	2007	2007
Balitc states and CIS*	235	224	199	14
Eastern Europe	49	45	40	2,8
Western Europe	89	79	73	5.2
Developing Asia	404	453	466	33
North Africa	20	23	23	1.6
Sub-Saharan Africa	134	161	196	14
Latin America and the Caribbean	89	134	149	11
North America	222	231	216	15
Oceania	33	49	46	3.3
Other regions	6	4	0	0
World	1 281	1 403	1 411	100

*CIS = Commonwealth of Independent States. Source: (FAO, 2009b)

Table 5. Pasture land by region 1961, 1991 and 2007

Region	Pasture			
		Area (Mha)		Share of global permanent pasture land (%)
	1961	1991	2007	2007
Baltic states and CIS*	302	327	362	11
Eastern Europe	20	20	17	0,5
Western Europe	70	61	59	1.7
Developing Asia	623	805	833	25
North Africa	73	74	77	2.3
Sub-Saharan Africa	812	824	834	25
Latin America and the Caribbean	458	539	550	16
North America	282	255	254	7.5
Oceania	445	431	394	12
Other regions	2	1	0	0
World	3 087	3 337	3 378	100

*CIS = Commonwealth of Independent States. Source: (FAO, 2009b)

2.1.3 Urban areas

Half of the world population today live in urban areas (United Nations, 2010). Data of how much land is occupied by built up areas range from 0.2-2.7 % (28-350 Mha) of the global land area whereof the majority of available studies estimated the urban area to less than 0.5 % (Potere and Schneider, 2007). Urban areas are estimated to increase from approximately 0.4 % of the global land area in 2000 to 0.7 % in 2030 and 0.9% in 2050 (Klein et al., 2009).

Today 70-80 % of the population in Europe, North America, Oceania and Latin America live in urban areas. Asia and Africa are the continents with the highest proportion of its population remaining rural (approximately 60 %) (Table 6). The high rate of urbanization in Asia and Africa however predict big changes of the future social structure in these continents. Along with increasing populations and economic growth in the developing countries the need for more and bigger residential- and industry areas are growing quickly. Between 2009 and 2050 the global urban population is estimated to increase from 3.4 to 6.3 billion. As a consequence the rural population is believed to reach a maximum of 3.5 billion in 2020 to thereafter decline to 2.9 billion in 2050. According to these projection 69 % of the world population will be urban by 2050. The largest increase of urban population is expected to take place in the cities and towns of currently less developed regions and be particularly big in Asia (United Nations, 2010).

Table 6. Urban population in 2009 and projections for 2050

Region	Urban population (%, 2009)	Urban population (%, 2050)
Africa	40	62
Asia	42	65
Europe	73	84
Latin America and Caribbean	79	89
North America	82	90
Oceania	70	75
World	50	69

Source: (United Nations, 2010)

The global urban expansion rate is estimated at 2 million hectares per year (FAO, 2006a). Historically cities were often founded close to good farmland areas why expansion of urban settlements often take place on high-quality crop-land (Ramankutty et al., 2006). Cities were estimated to occupy some 3 % of the global arable land in 2000 (Tilman et al., 2006). Although urban areas still cover a relatively small part of the global surface, expanding human settlements could have serious implications for food security in land scare countries due to loss and competition of valuable crop-land. South Asia is an example of a region where large proportions of the land with crop production potential has been occupied by urban settlements (Bruinsma, 2003). The annual loss of crop-land in the developing countries due to urban settlement is estimated to 1-2 million hectares (Döös, 2002). Assuming that future expansion of built-up areas would replace current crop-land, additionally 67 milllion hectares of crop-land, mainly in the developing countries, will be lost by 2050 (Nellemann et al., 2009). Similar projections from FAO estimated the conversion of land for non-agricultural purposes to be almost 90 million hectares (Bruinsma, 2003). Angel et al. (2005) have made comparable estimates, suggesting that cities may occupy 5-7 % of total arable land by 2030.

2.2 Reliability of land use data

Availability of land use data is essential for understanding how human activities impact on the global environment and ecosystems, why there is a need for accurate information on land use and its dynamics. From the literature, it is however obvious that quality of land use data is varying and that used methodologies for obtaining information on land use is challenged by a number of uncertainty factors which are affecting the overall reliability of the results (Foody, 2002, Fritz and See, 2008, Fischer, 2009, Herolda et al., 2007, Ramankutty et al., 2008).

The traditional way of obtaining land use data has been based on the use of national agriculture statistics. Land use data disseminated by the FAO is an example of data retrieved in this manner. FAO data is based on national surveys and questionnaires that are collected from each member state on annual basis to get an overview of the global land use system. Since the 1970s information of how land is used can also be obtained by using remote sensing from satellites in space (Ramankutty et al., 2006). The technique, which can deliver continuous data over time with high resolution, has provided valuable information in the field of land cover and land use research during the last decades. However both agricultural inventory data and satellite derived land use data include uncertainty factors and sources of errors (Ramankutty et al., 2008) why the understanding of land use and its dynamics still is limited.

The reliability and accuracy of official land use data based on agricultural inventory is depending on the quality of the surveys performed in each member country and has among other things been criticized for underestimating agriculture areas in developing countries (Ramankutty et al., 2006, Young, 1999). Lack of harmonization of land use definitions is one of the problems contributing to the complexity of interpreting data. In the literature there is often no clear distinction between different land use categories such as agriculture land and cultivated land or grassland and pasture land. Land use definitions moreover often vary from country to country, why it can be hard to combine and compare data from different studies (Ramankutty et al., 2008). Misclassification is another problem arising from the complexity of distinguishing one land use category from another. The continuous nature of landscapes has no clear boundaries, which makes it hard to classify the landscape into defined categories. Some landscapes are moreover used for several purposes making it even harder to distinguish one land category from another. The fact that land use activities can change quickly over times is another challenging factor resulting in a need of updated data, which might not always be available (George and Nachtergaele, 2002).

Ramankutty et al. (2008) exemplifies the variation in land use data with examples from Saudi Arabia for which FAOSTAT reports pasture areas 3500 times bigger than subnational census data, for year 2000. In the PAGE-study (Wood et al., 2000) variations in land use data was visualized by comparing data for global agriculture land for 1992-1993 obtained from FAOSTAT with their own satellite estimates. The comparison showed that FAO data of global agriculture area was 30 % greater than the satellite estimates. Frolking et al. (2002) further suggests that crop-land areas in official country scale statistics generally is underreported and can be 40 % smaller than estimates obtained from remote sensing analysis.

The limitations in reliability of land use data is important to have in mind also when reading and interpreting the content of this report. The majority of the presented land use data are adapted from agriculture statistics from FAO. If the statement that official agriculture data from FAO overestimate agriculture areas is true, this could be an important source of error that has to be kept in mind. The limitation in reliability of available land use data demonstrates a need for continued development of more accurate methods for land use analysis.

2.3 Use of cultivated land

2.3.1 By commodity group

Several of the world's major crops are used as feedstock in various sectors of applications including food, feed and fuel production. Agriculture products can additionally be used for fibre production in the textile industry, such as in the case for cotton, flax and hemp, and as feedstock in the chemical industry. This report is mainly focusing on land use conflicts between food, feed and biofuel why a deeper analysis of agriculture products for other purposes will not be included. Due to the fact that the same crop can be used for many different purposes it is complex to estimate the distribution of agriculture land by production sector. Data from the literature however suggest that about 2 % (27 Mha) of global cultivated land is used for production of biofuels (data for 2007) (Bustamante et al., 2009), 33 % (500 Mha) is used for feed production (data for 2006) (Steinfeld et al., 2006) and approximately 62

% (956 Mha) for crops dedicated to direct human consumption (data for 1999) (Ravindranath et al., 2009) (Figure 4). The group called other uses is mainly constituted by crops used in the chemical and textile industry. As the above data refers to the distribution of land in the past ten years, the distribution of cultivated land by commodity group has most likely changed until today. As no more recent data has been found in the literature, these data are used to give an idea of the land use proportions between the three sectors.

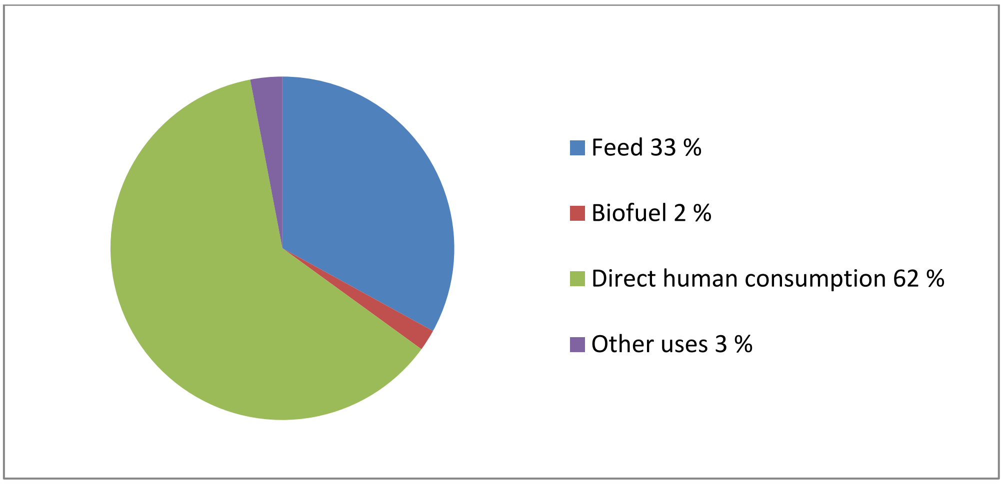


Figure 4. Distribution of cultivated land between crops for feed, biofuel and direct human consumption (Bustamante et al., 2009, Steinfeld et al., 2006, Ravindranath et al., 2009).
Total cultivated land = 1527 Mha (in 2008).

2.3.2 By cultivated crop

To investigate the distribution of cultivated land, in terms of cultivated crops, is complex for various reasons. The amount of land dedicated for cultivation, defined as cropland, is normally expressed as the sum of arable land and land under permanent crops. According to the FAOSTAT database global crop-land covered approximately 1527 million hectares in 2008 (FAOSTAT 2010). This area includes temporary meadows for mowing or pasture and land temporarily in fallow.

Statistics of how much land different crops occupy is instead expressed as harvested area, meaning that crop-land is counted twice in case of multiple cropping. The harvested area of a crop can be obtained if the production quantity and yield is known. No data however exists on the area of total harvested land (Bruinsma, 2009), why a ratio between the harvested area of a defined crop and total harvested area cannot be obtained. In a similar way there is no data available (of knowledge of the authors of this report) for the arable or cropped area for single crops. It is not certain whether the data set for global crop-land is compatible with the areas for total harvested land (Bruinsma, 2009). If the harvested area of major commodity groups (cereals, oil crops, pulses, roots and tubers, fibres, fruit, vegetables and sugar crops) in 2009 (FAOSTAT 2011) are summed this equals 1268 million hectares, corresponding to 83 % of global crop-land in 2008.

In Figure 5 the distribution of harvested area between major crops is visualised when the total harvested area is assumed to equal global crop-land in 2008. In Figure 5 the difference in area between the two data sets is expressed as “unknown”, and composes 17 % of total arable land.

What this group consists of is not certain but temporary fallow land could explain part of the difference. The area occupied by temporary fallow land, which is defined as land that has been fallow for less than five years, is not of knowledge to the authors of this report, but the total fallow land (temporary and permanent) in a global perspective has been estimated to cover 440 million hectares, an area equivalent to 29 % of global crop-land in 2000 (Siebert et al., 2010).

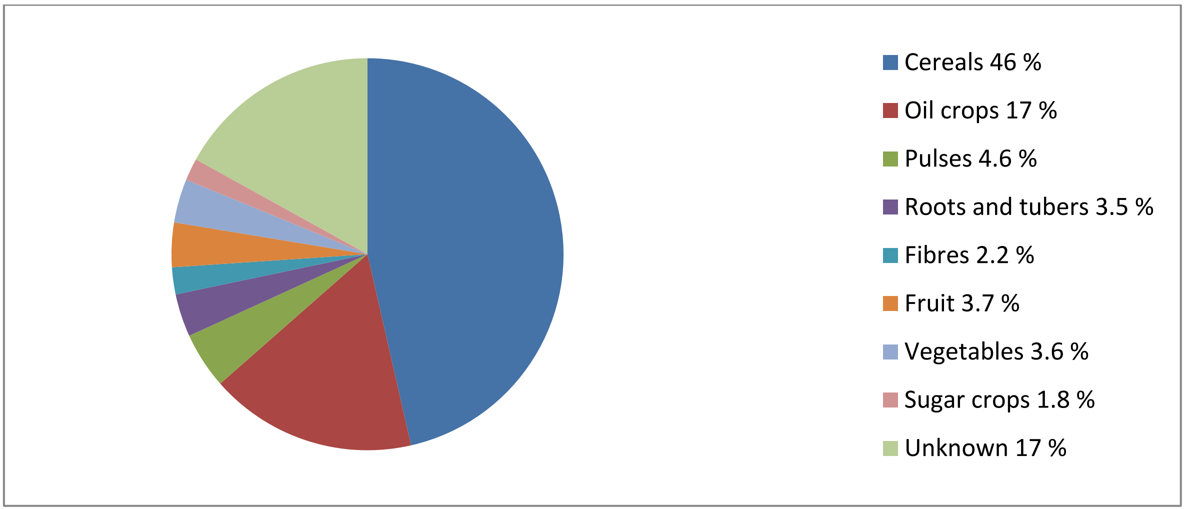


Figure 5. Distribution of harvested area between major crops
Data are based on harvested area in 2009 and total harvested area is assumed to equal global cropland in 2008 (1527 Mha). Source: FAOSTAT 2010.

Cereals is the dominating commodity group both in respect of harvested area and produced quantity. Almost half of the global harvested area (709 Mha) is used for cultivation of cereals (Figure 5). The global production of cereals was approximately 2500 million tonnes per year in 2009 (FAOSTAT 2010). During the last decades the harvested area of cereal production has decreased in particular in the developed world simultaneously as an increase has been seen in the developing world (Table 7).

Oil crops occupy about 17 % (261 Mha) of the global harvested area (data for 2008) (FAOSTAT 2010) (Table 7) and is the fastest growing sub-sector in global agriculture (FAO, 2006b). Major drivers for the expansion has been an increased demand for direct consumption of vegetable oils in the developing countries, increased use of oil crops as feed in the livestock production and increased utilisation of oil crops for non-food uses, such as biodiesel and biochemicals. The production of oil crops, which has increased from about 34 to 110 million tonnes between 1970 and 2000, has been responsible for a substantial part of the agricultural land expansion seen in the developing world during the last decades (FAO, 2006b).

Pulses, roots and tubers, fruit, vegetables and sugar crops together occupy about 19 % of the global harvested area (Table 7). For several of these food groups (pulses, root and tubers and sugar crops) a trend of a moderate decrease in harvested area has taken place in the developed world during the last decades, whereas a small increase has been seen in the developing countries. Production of sugar crops, in particular, has increased substantially (67% between 1975 and 1998) in the developing world (Table 7). Ethanol production, primary from sugar cane, has been a strong driver behind the observed increase in production of sugar crops.

Table 7. Change in harvested area expressed in Mha

	Developing countries			Rest of world		
	1974/76	1997/99	Change (%)	1974/76	1997/99	Change (%)
Cereals	406	441	+8,6	306	242	-21
Roots and tubers	33	40	+21	15	11	-27
Pulses	53	60	+13	10	9	-10
Sugar beet and cane	12	20	+67	9	7	-22
Fibre crops	30	28	-6,7	9	9	0
Oil crops	70	120	+71	38	63	+66
Total above	603	708	+17	387	342	-12

Source: Adapted from (Bruinsma, 2003)

2.3.3 Agricultural crops in production of food, feed and biofuel

Direct human consumption of agricultural crops contributes with over 80 % of dietary energy supply in the world. Cereals are the most important food group in perspective of energy supply for humans and is providing about half (47 %) of the dietary energy intake. Oil crops constitute another important food group providing about 11 % of the human calorie intake. Pulses, fruits and roots and tubers together provide around 13 % of the human energy intake. The consumption of cereals, roots and tubers represents a mainstay in the diet in many developing countries and is estimated to contribute with up to 80 and 56 % of the energy supply in poor regions (FAO, 2009c).

Harvested crops used as feed in livestock production can be divided into forages and concentrates. Forages include cellulose rich crops such as hay and ensilage whereas feed concentrates, produced from various feedstock, is used to provide concentrated amounts of protein and energy (Dale et al., 2009). Cereals and brans are the most common used feedstock for feed (FAO, 2009b). Approximately 40 % of the grain harvest is fed to livestock (Aiking, 2010). Also significant quantities of root crops are used as feed, approximately 14 %, 36 % and 27 % of the world production of potatoes, sweet potatoes cassava is estimated to be used as animal feed (FAO, 2006b). Oil crops and pulses are other big feed crops widely used due to their high content of energy and protein. The main feedstock from this group is the soya bean, mainly produced in the United States, Brazil and Argentina. About three quarters of the globally produced soy is used as feed concentrate for animals (Aiking, 2010). Another commonly used feed crop from this group is the oil palm originating from South East Asia.

Various crops are used as feedstock for biofuel production. For ethanol production sugar cane from Brazil and maize from the United States are the dominant crops. Ethanol production from sugar cane in Brazil and maize in the United States occupied 5.1 and 2.9 million hectares, respectively in 2006 (Goldemberg and Guardabassi, 2009). Other crops used for ethanol production include sugar beet, wheat, barley, cassava and rice (Connor and Hernandez, 2009). For biodiesel the most used feedstock are rapeseed in the EU, soybean in the United States and in Brazil and palm-, coconut- and castor oil in tropical and subtropical countries (FAO, 2008b).

2.4 Summary: Present land use

Competition for land between different land uses have resulted in a continuous dynamic between forest, agriculture land and urban areas. According to data from FAO, forest and agriculture land roughly cover two thirds of the global land area (30 % and 37 %, respectively) and remaining land is distributed between urban areas (< 1 %) and other land (31 %) (Figure 6A). Historically the overall trend in global land use change has been increasing agriculture areas and urban areas at expense of a decreasing forest cover. Also current trends show a predefined hierarchy when allocating land use, where urban areas generally expand on farm land and forest is converted to agriculture areas. On global scale total agriculture land areas are expanding, as a consequence of increasing areas for cultivation and pasture land in developing countries. In the industrialised world on the other hand land areas under agriculture are decreasing.

Availability of land use data is essential for understanding how human activities affect the global environment and ecosystems. From the literature, it is however obvious that quality of land use data is varying and that used methodologies for obtaining information on land use is challenged by a number of uncertainty factors. The limitations in reliability of land use data is important to have in mind when reading and interpreting the content of this report. The limitation in reliability of available land use data also demonstrate a need for continued development of more accurate methods for land use analysis.

Several of the world's major crops are used as feedstock in various sectors of applications including food, feed and fuel production. Due to the fact that the same crop can be used for many different purposes it is complex to estimate the distribution of agriculture land by production sector. Data from the literature suggest that about 2 % of the global cultivated land areas are used for production of biofuels, one third is used for feed production and almost two thirds for crops dedicated for direct human consumption. Figure 6B visualises the estimated distribution of agriculture land between pasture land and cultivated land allocated to food, feed and energy crops. Cereals followed by oil crops are the dominating commodity groups both in respect of harvested area and produced quantity. The large crop areas occupied by cereals and oil crops reflect the importance of these crops for human food supply as well as major feedstock for feed and biofuel production. Figure 6C shows a simplified picture of the distribution of global harvested area between major agricultural crops.

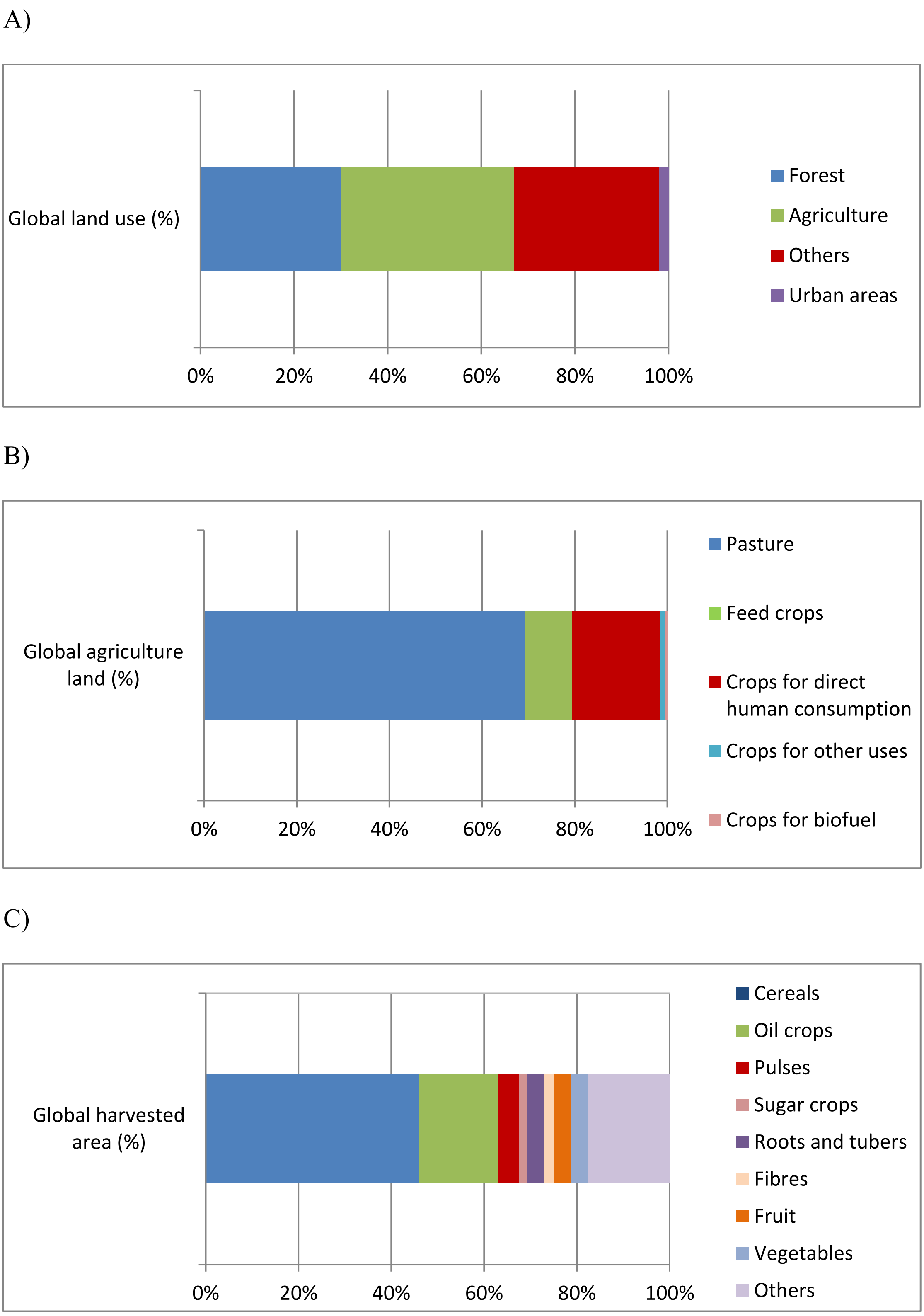


Figure 6. Distribution of global agriculture land
A) Global land use distribution. B) Distribution of global agriculture land. C) Distribution of global harvested area. Data are based on references in chapter 2.

3. DRIVERS FOR LAND USE CHANGE

The dynamics between forest, agriculture and urban land areas described in chapter 2 shows that significant changes in land use have occurred during the last centuries. Changes in land use is propelled and affected by several factors. In chapter 3 important drivers for land use change will be identified and discussed as well as some additional challenges, which can have impact on future land use. The identified drivers and challenges are; population growth (3.1), increased demand for livestock products (3.2), increased demand for bioenergy (3.3), land degradation and climate change (3.4).

Box 2. Definitions for country groups

The division between developed and developing countries have been criticized for being an old-fashioned way of describing the differences between countries level of development. In the literature classification of regions into country groups is however still a common way of presenting statistics.

The country groups used by FAO are according to the standard country and area codes specified in the United Nations (UN) classification (United Nations, 2011), in which it is stated:

"The assignment of countries or areas to specific groupings is for statistical convenience and does not imply any assumption regarding political or other affiliation of countries or territories by the UN. The designations "developed" and developing" do not necessarily express a judgement about the stage reached by a particular country or area in the development process."

"There is no established convention for the designation of "developed" and "developing" countries or areas in the UN system. In common practice, Japan in Asia, Canada and the United States in northern America, Australia and New Zealand in Oceania, and Europe are considered "developed" regions or areas. In international trade statistics, the Southern African Customs Union is also treated as a developed region and Israel as a developed country; countries emerging from the former Yugoslavia are treated as developing countries; and countries of Eastern Europe and of the Commonwealth of Independent States in Europe are not included under either developed or developing regions."

The list of countries and the standard country groups stated in the UN classification are shown in Appendix 1.

3.1 Population growth

The rate of population growth is directly decisive for future global demand of food and energy. Between 1960 and 1990 the world population almost doubled at the same time as arable land per person declined from 0.43 hectares in the beginning of the 1960s to 0.26 in the end of the 1990s. The growth rate of world population peaked in the end of the 1960 at 2.04

% per year. Since then the population has continued to increase but with a lower growth rate (Table 8) (FAO, 2006b). Today the population is increasing by approximately 200 000 people each day, corresponding to an annual increase of more than 70 million people. According to the medium variant of demographic projections the world population is estimated to reach 8.3 billion by 2030 and surpass 9 billion by 2050. United Nations Population Division has in addition to the medium variant developed a low and high projection of population growth. With the low variant the global population would be about 8 billion by 2050 and with the high variant it would be over 10 billion (United Nations, 2009).

Table 8. Projected* population growth rate until 2050

	2000	2015	2030	2050
Population (billion)	6.1	7.2	8.3	9.3
Annual growth rate (million/year)	79	76	67	43
Annual growth rate (%)	1.35**	1.1	0.8	0.5

* Projections according to the medium variant. **Mean for 1997/1999. Source: (Bruinsma, 2003).

The future population growth will almost exclusively take place in the developing world. In the more developed regions only a modest increase is expected from 1.23 billion in 2009 to 1.28 billion in 2050. During the same period the African population is expected to double and the Asian population to increase by more than one billion people (Table 9) (United Nations, 2009). People with poor economic circumstances in general have more children per woman (Dasgupta, 1995) which is one explanation why population growth is greatest in regions with high prevalence of poverty (Koning et al., 2008). In total the population in the developing world is expected to increase from 5.6 billion people in 2009 to 7.9 billion in 2050. The biggest population growth is projected in Asia whereas the highest population growth rate is expected in Africa (United Nations, 2009).

Table 9. Distribution of the world population in 2009 and 2050

	2009 (million)	2009 (%)	2050* (million)	2050* (%)
World	6829	100	9150	100
Africa	1010	15	1998	22
Asia	4121	60	5231	57
Europe	732	11	691	8
Latin America and Caribbean	582	9	729	8
North America	348	5	448	5
Oceania	35	1	51	1

*Projections according to the medium variant. Source: (United Nations, 2009).

As shown in Table 8 the population growth rate is estimated to decline from 1.35 % per year in 1997/1998 to 0.50 % per year in 2050. Also in the developing countries, where the biggest population growth is projected, growth rates are expected to decline during the coming decades (Bruinsma, 2003). The global mean fertility levels are estimated to decline from todays 2.73 to 2.05 in 2045-2050. The most drastic change in fertility levels is expected in the least developed countries where the number of children per woman is believed to almost halve from 4.39 to 2.41. To achieve such reductions big progress and development on various levels is needed. If instead todays fertility levels persists the increase of world population could be considerably larger, maybe twice as big as currently expected, implying a population of 9.8 billion people only in the developing world by 2050 (United Nations, 2009). The population growth rate will therefore be highly dependent on the efficiency in global poverty reduction which in turn will determine the future size of demand for food and energy in the world.

3.2 Increased demand for livestock products

Population growth, combined with income growth and urbanization during the last decades have been driving a rapid expansion of the livestock sector, described as the livestock revolution (Delgado et al., 1999). This section describes trends and drivers for livestock production and consumption as well as projected implications that an increased demand for livestock products could have on future land use change.

3.2.1 Consumption

In year 2006 global meat consumption reached 172 million metric tons per year which was a fourfold increase compared to levels in the beginning of the 1960s (Deckers, 2010). In many industrial countries consumption patterns with high shares of animal products have been common for a long time, in North America for example the per capita consumption of meat surpassed 100 kilograms per year already in 1970 (FAOSTAT 2004 through earth trends 2007). The increased consumption of animal products in the industrial countries has started to stagnate but during the last decades a strong trend of increased consumption of livestock products has instead been seen in the developing countries. According to the FAO the per capita consumption of milk in the developing countries has almost doubled, meat consumption more than tripled and egg consumption increased by a factor five, during the last fifty years. Overall intake of livestock products has increased in all developing regions except Sub-Saharan Africa. Intake levels of animal products are however still substantially larger in most developed countries compared to in developing regions (Table 10) (FAO, 2009b).

Intake of poultry and pork has increased more than other meat groups whereas increase in beef consumption has been more modest (Kearney, 2010). Table 10 shows the increase in consumption of livestock products during the last three decades. The greatest increase of meat consumption has occurred in East and Southeast Asia followed by Latin America. China alone accounted for 57 % of the total increase in meat consumption in the developing countries between 1980 and 2002 (FAO, 2009b). Figure 7 shows the strong trend of increased meat consumption in these regions between 1961 and 2000.

Table 10. Per capita consumption of livestock products in kilograms for 1980 and 2005

	Meat		Milk		Eggs	
	1980	2005	1980	2005	1980	2005
Developed countries	76	82	198	208	14	13
Developing countries	14	31	34	51	2.5	8
World	30	41	76	82	5.5	9

Source: (FAO, 2009b)

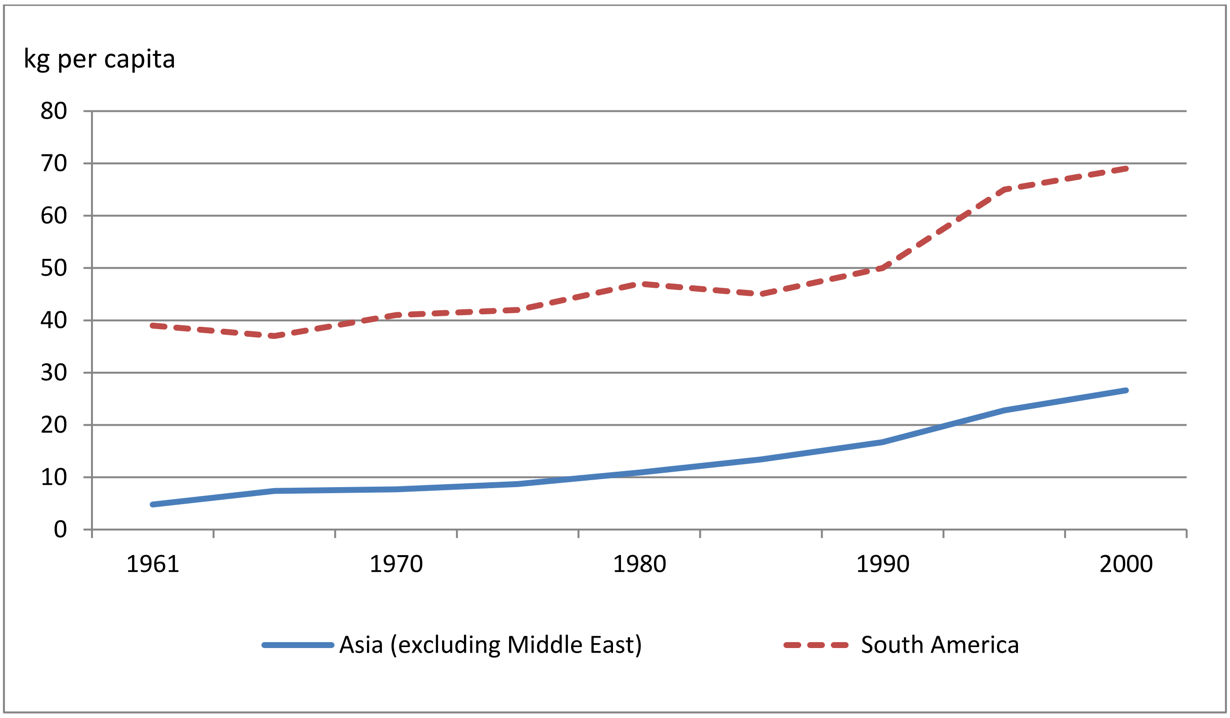


Figure 7. Per capita meat consumption in Asia and South America, 1961-2000
Source: Data from FAOSTAT 2004 through Earth Trends, World Resource Institute 2007

Population growth and increased total calorie availability partly explains the increased consumption of animal products. Other factors that are considered to drive the change towards more meat based consumption patterns are economic growth and urbanization. The relationship between per capita income and meat consumption is strongly positive, especially for income growth at low income levels (FAO, 2009b). The economic expansion that has taken place in many developing countries during the last decades, resulting in rising per capita income and a growing middle class, has consequently been strong drivers for increased intake of animal products (Steinfeld et al., 2006). In countries with high income levels that already eat a large share of animal products the relationship is less pronounced and can even be negative. Cheap inputs and progress in technology and efficiency has furthermore resulted in animal food becoming cheaper which have increased the accessibility also for people with lower income (FAO, 2009b).

Despite the increased intake of animal products in the developing world still big differences exist between different regions. In North America per capita meat consumption was 121 kilograms in 2000, corresponding to 330 grams per day (Figure 8). In Europe and South America meat intake levels were approximately 190 grams per day and in Asia and Sub-Saharan Africa corresponding levels were 73 and 36 grams per day respectively (4.5 and 9 times less than intake levels in North America) (FAOSTAT 2004 through Earth trends 2007). The presented data for consumption of meat refer to the annual supply of meat available for consumption per person, as reported in FAO Food Balance Sheets (FAO, 2011a). The data include both imports and exports and are expressed in carcass weight which exclude offal and hide but include most bones (Westhoek et al., 2011). This value will overestimate the actual amount of meat ingested per person (due to bone weight and retail and household losses) but is usually applicable to use when calculating the environmental impact from meat consumption.

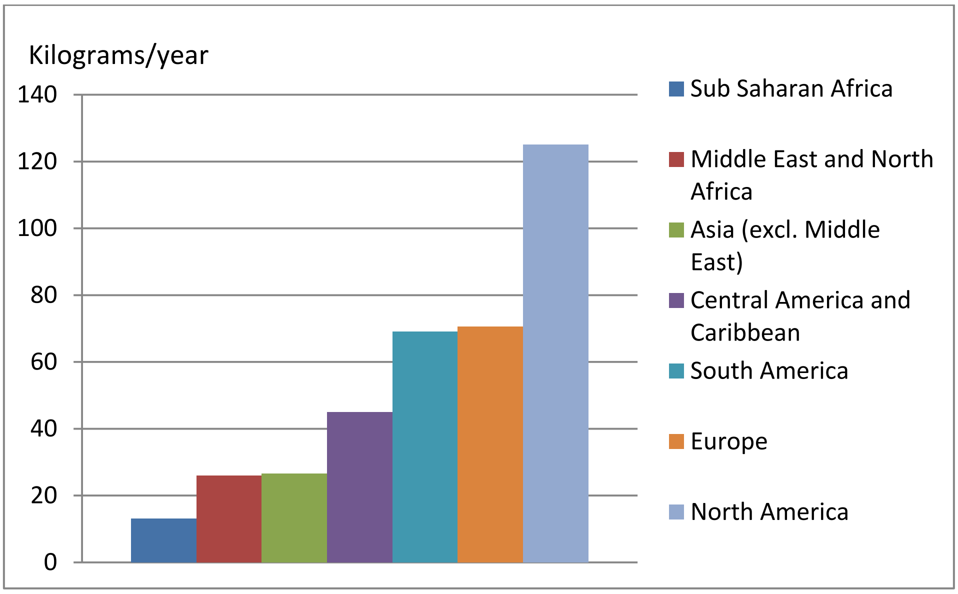


Figure 8. Per capita meat consumption in year 2000
Source: FAOSTAT 2004 through Earth Trends, World Resource Institute 2007.

The increase in demand for livestock products is believed to continue for the next three decades (Thornton, 2010), although at slower growth rate (FAO, 2006b). Earlier projections from FAO estimated that the global per capita consumption of meat will rise from 37 kg at present to 52 kg in 2050 (a change from 101g to 143 g per day) (Bruinsma, 2003). In another report global meat consumption was projected to increase by 19 % between 2009 and 2018 (OECD–FAO, 2009). Rosegrant and Thornton (2008) further projected that global per capita demand for meat will increase with 6-23 kilograms, according to the region, until 2050 relative consumption levels in 2000. Most of the increased demand for animal products is believed to take place in developing countries, with the biggest absolute increase in Latin America and the Caribbean and the East and South Asia (OECD–FAO, 2009, Rosegrant and Thornton, 2008).

3.2.2 Production

Increased demand for animal products during the last decades has driven a rapid increase in livestock production. Between 1961 and 2007 the global poultry production almost grew tenfold at the same times as pig production increased almost fivefold and production of ruminants roughly doubled. The biggest increase in meat and egg production occurred in East and South East Asia and South America (Figure 9), whereas South Asia, with India as the biggest producer, has dominated the increase in milk production. The increase in livestock production has mainly occurred in the developing countries, which since 2007 together produce more meat and eggs than the developed world (FAO, 2009b). China, Brazil and India, the biggest producers of animal products in the developing world, mainly accounted for this development (Steinfeld et al., 2006). In China for example the production of meat increased six fold during the past 30 years and now account for almost one third of the world meat production (FAO, 2009b). In other regions such in Oceania and Africa the increase in meat production has been more modest whereas a trend of reduced animal production was noted in Europe between the 1990´s and the 2000´s (FAOSTAT 2009).

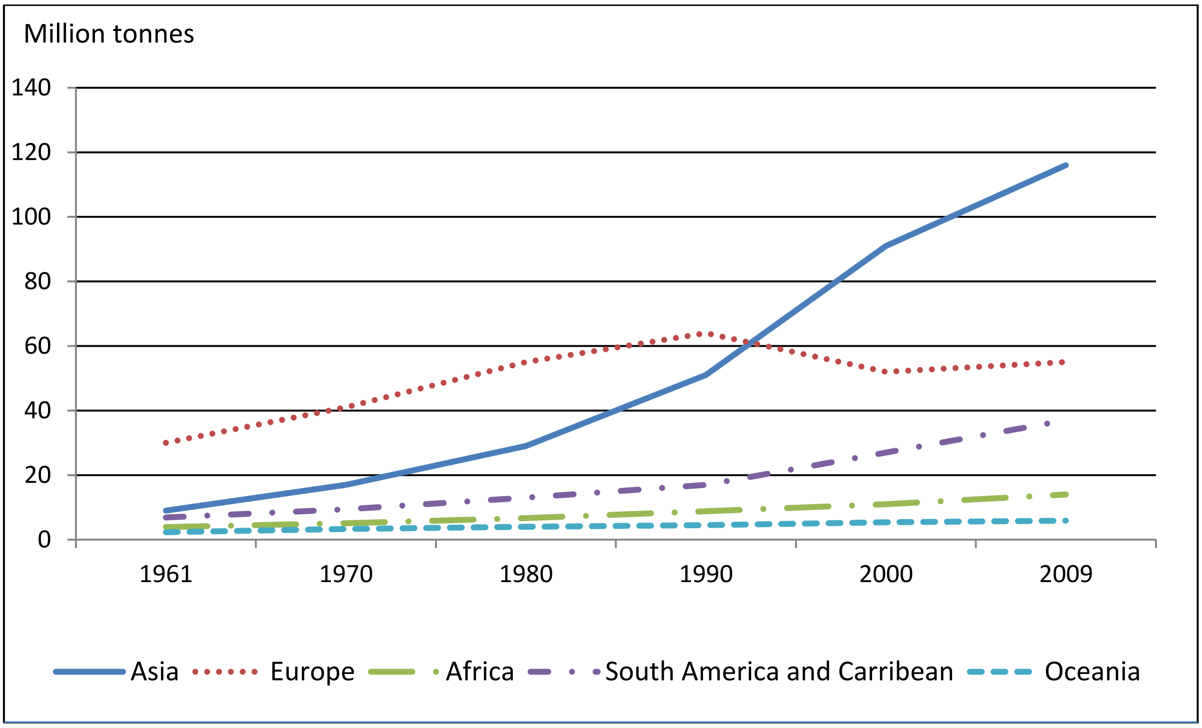


Figure 9. Meat production by region 1961-2009
Source: FAOSTAT 2009

The increase in livestock production has been a result of increased number of animals and increasing yields. During the past thirty years the number of chickens in the world grew 2.6 times and the number of pigs and cattle increased by 18 and 14 % respectively (Table 11) (FAOSTAT 2010). Technological development in the livestock sector has enabled increased output per animal especially in poultry and egg production as well as the pork and diary sector. Generally the number of livestock however increased faster than the yields between 1980 and 2007, meaning that the majority of the increased production was attributed by an increased number of animals (FAO, 2009b). Projections have shown that global livestock production will continue to grow with 85 % between 2000 and 2030 (World Bank, 2008). Others have estimated that the worldwide yearly meat production will double (Steinfeld et al., 2006) and the global population of cattle will increase from 1.5 billion to 2.6 billion between 2000 and 2050 (Rosegrant and Thornton, 2008).

An increased number of animals could theoretically increase land use pressure by expanding pasture areas and through an increased demand for feed crops. Increased intensity in agriculture has resulted in higher yields and reduced demand for land per amount of produced feed crops. Simultaneously a shift from extensive livestock production towards mixed and non-grazing production systems is taking place, reducing the demand for land per kilogram produced meat (FAO, 2009b). In the developed countries intensification of the livestock production has decreased the areas for grazing land during the past five decades (FAO, 2009b). As availability of land gradually become scarcer and the livestock sector become more intensive a similar development could be expected also in the developing countries. Another trend which will affect the demand for land is the gradual increase in consumption of monogastric meat. Production of monogastrics has been growing faster than the production of ruminants during the past decades. The fastest growing sub sector, both in respect of produced meat and number of animals, has been the poultry sector followed by the pig meat production (FAO, 2009b). Due to the fact that monogastrics have higher feed conversion and fertility rates than ruminants, production of poultry and pig meat demand less land than beef and meat from other ruminants. On the other hand monogastrics does not have the ability to digest cellulose why they need higher shares of feed concentrates compared to ruminants. The big increase in production of monogastrics and the intensification of the livestock sector overall has resulted in a rapid increase in use of feed concentrates.

Table 11. Number of animals in the world (in million) and relative change 1980-2009

	Chickens	Pigs	Cattle	Sheep
2009	18555 (+157 %)	941 (+18 %)	1382 (+14 %)	1071 (-3 %)
2000	14469	899	1315	1059
1990	10633	856	1298	1208
1980	7216	798	1217	1099

Source: FAOSTAT 2010

The projected increase in demand of livestock products thus has to be considered as a potential threat of increased land use pressure. Increased livestock production will however not necessarily lead to a net increase in demand of global agriculture land. The growth in livestock production will mainly take place in the developing world where it theoretically could lead to loss of forest and other land with high biological value. Whether an increased production will result in expansion of agriculture land will among other things depend on the economic growth and development of the agriculture sector in these regions. Part of the increase in livestock production will come from an increased intensification of the crop and livestock sector, resulting in a reduced demand for pasture land in favour of arable land. A shift from extensive towards mixed and non-grazing production systems in combination of an intensified crop production will have implications on the environment and animal welfare, which will be further discussed later in this report (see 5.2).

3.3 Increased demand for bioenergy

Use of biomass for energy purposes is generally divided into traditional and modern production of bioenergy. Traditional bioenergy refers to the use of biomass in open hearts and stoves for cooking and heating, whereas modern bioenergy is defined as the generation of biomass intended for production of heat, electricity or biofuels (Smeets et al., 2007). Feedstock for production of bioenergy can be generated from various biomass sources such as fibre and wood process residues, energy crops and agricultural waste. The majority of current biomass used for energy purposes originates from by-products and co-products in existing systems for food, fodder and fibre production (FAO, 2008b). In addition dedicated energy crops such as sugar cane, wheat, maize and woody bioenergy crops has emerged as new sources of demand for agriculture products, which put additional pressure on arable land. In this section current use, trends and future potential of bioenergy, mainly focusing on grown energy crops, will be summarized.

According to the International Energy Agency (2006), 45 EJ of primary solid biomass was consumed in 2005 covering around 10 % of the total world energy use (FAO, 2008b). The utilization of bioenergy vary between 3-4 % of total energy use in most developed countries up to 34 and 60 % in Asia and Africa respectively (MAPA, 2006). In the developing world solid biomass such as fuelwood, charcoal and animal dung is used primarily for cooking and heating. Solid biomass for such traditional uses represent approximately 99 % of all used bioenergy (FAO, 2008b). In the developed world an increased demand of commercial bioenergy has instead been noted mainly as a response to the increased use of biofuel in the transport sector. Liquid biofuels currently account for about 3 % (data for 2008) of the global share of road fuel demand (International Energy Agency, 2010).

Climate mitigation and energy security has been two strong drivers behind the recent growth of the biofuel sector (FAO, 2008b). The transport sector, which accounts for around 28 % of the total energy use, is today to 98 % dependent on fossil fuels (Statens Energimyndighet, 2009). The use of biofuels from crops has been identified as a possible way of reducing climate impact of transportation fuels. Bioethanol and biodiesel production primarily made from maize, sugar cane and vegetable oils are the dominating biofuels markets. During the last ten years production of ethanol and biodiesel has grown steadily, with a 30 and 40 % increase seen in the respective sector between 2007 and 2009 (Table 12) (REN 21, 2010) and a 70 % increase in the global bioenergy consumption between 1950-2000 (Fernandes et al., 2007). The United States and Brazil are accounting for almost 90 % of the total ethanol production whereas the European Union, representing nearly 50 % of the total output, is dominating the production of biodiesel (Table 13) (REN 21, 2010). In the United States ethanol production has increased by a factor five between 1997 and 2007 (Energy Information Administration, 2008) and during the same period production of biodiesel increased ten times in the European Union (EBB, 2008). Current global levels of ethanol and biodiesel are estimated to 76 and 17 billion litres per year (Table 12) (REN 21, 2010).

Table 12. Annual production of ethanol and biodiesel (in billion litres)

	2007	2008	2009
Ethanol	53	69	76
Biodiesel	10	15	17

Source: (REN 21, 2010)

Table 13. Biofuel production by country in 2007 (in million litres)

	Ethanol	Biodiesel	Total
United States of America	26500	1688	28188
Brazil	19000	227	19227
European Union	2253	6109	8361
China	1840	114	1954
Canada	1000	97	1097
India	400	45	445
Indonesia	0	409	409
Malaysia	0	330	330
Others	1017	1186	2203
World	52009	10204	62213

Source; based on (FAO, 2008b), data from the OECD-FAO AgLink-Cosimo database.

Global energy demand for bioenergy is projected to increase by 45% between 2006 and 2030 and has been estimated to double between now and 2050 (Hoogwijk et al., 2003). In many countries policies that support production and consumption of bioenergy has been set up as strategies to decrease the dependency of fossil fuels and reduce greenhouse gas emissions. Examples of used policy measures benefitting the biofuel sector are production supports in form of agricultural subsidies combined with blending mandates, subsidies and tax incentives which stimulate demand on the consumption side (FAO, 2008b). In 2007, the European Council introduced an ambitious directive on renewable energy for 2020, including binding targets of a 20 % share of renewable energy in overall energy consumption and 10 % share of biofuels in the transport sector (Commission of the European Communities, 2007). Similar bioenergy targets have been made in several other countries such as in Brazil, China and India (Table 14) (FAO, 2008b, Ravindranath et al., 2009). Proposed policy incentives in various countries worldwide suggest that the observed trend in OECD countries, with growth in biofuel production as a result of government support, may expand to include a growing number of countries, including developing countries.

Table 14. Biofuel targets in major countries/regions

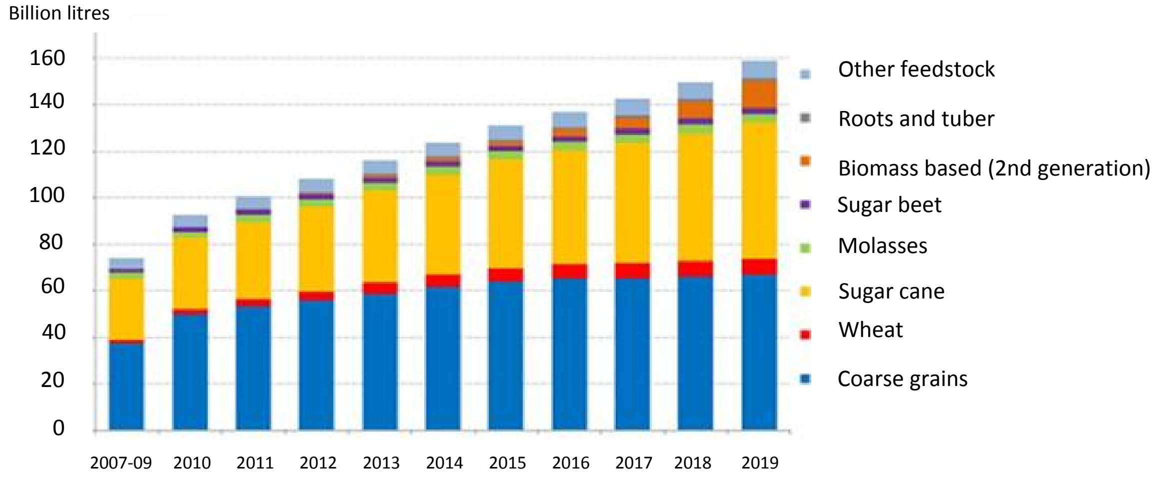
Country/region	Mandatory, voluntary or indicative targets
European Union	10 % by 2020
Japan	A goal to reduce fossil duel dependence of transport sector from 98% to 80& by 2030
New Zealand	3,4% target for both gasoline and diesel by 2012
United States	20,5 billion gallons by 2015, 35 billion gallons by 2022
China	10 Mtonnes ethanol by 2020, 2 Mtonnes biodiesel by 2020
India	20% ethanol blending in gasoline by 2017, 20 % biodiesel blending by 2017
Indonesia	3% biofuels in energy mix by 2015, and 5% 2020
Thailand	10% ethanol blend by 2012, 10% biodiesel blend by 2012
South Africa	2% of biofuels by 2013

Source: (Fischer, 2009)

Due to rising oil prices and government support the growth in production of biofuel is expected to continue. Various attempts have been made to estimate the future potential of biofuels. The World Energy Outlook 2010 (International Energy Agency, 2010) project that global biofuel use will increase more than four-fold between 2008 and 2035, resulting in an increased share of road fuel demand from 3 to 8 %. According to the FAO-OECD projections global ethanol production will increase from 75 to 160 billion litres and global biodiesel production from 15 to 40 billion litres from 2007/9-2019 (

Figure **10**) (OECD–FAO, 2010). Others have estimated that the total use of bioenergy will account for 20 % of the global energy supply in 2050 (Destouni and Frank, 2010). According to the Environmental Outlook to 2030 by OECD (2008), global areas for biofuel crops will increase by 242 % between 2005 and 2030, under current policies.

A)



B)

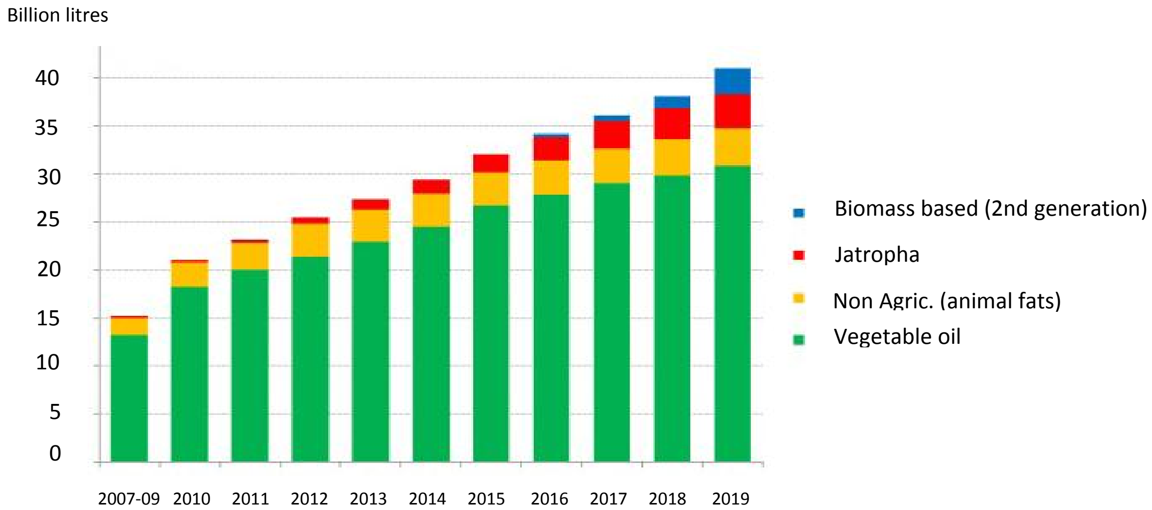


Figure 10. Global ethanol (A) and biodiesel (B) production according to the OECD- FAO Agricultural Outlook 2010-2019
Source: (OECD–FAO, 2010)

The production of biomass-based fine and bulk chemicals may be another reason for increased demand of biomass in the future. A great need of a transition towards more sustainable alternatives has been identified in the chemical industry (Tufvesson, 2010). In some countries incentives have been developed for a transition from fossil-based chemicals to chemicals based on renewable resources. Predictions have shown that a substantial increase in bio based production can be expected in the future (BCC, 2005, EuropaBio, 2003, Freedonia, 2005). Some of the increase in bio based chemicals could come from co-production with biofuels and other bio-based energy carriers in bio refineries.

Many parameters, such as future demand, area efficiency, choice of feedstock, development of extraction and conversion methods, will affect the proportion of agriculture land used for energy crops. Opportunities suggested to minimize land and resource constrains from biofuel production include increased use of residue biomass (Hoogwijk et al., 2003) and increased cultivation on marginal and abandoned land (see 5.1). The introduction of second generation biofuels from cellulosic feedstock, assumed to enter the market by around 2020 (International Energy Agency, 2010), is believed to enable further reduction of land use conflicts. Second generation biofuels presents several advantages over first generation crops including higher yields and increased ability of using degraded soils where crops for food production are unsuitable (FAO, 2008b). Other benefits related to second generation techniques are that they are more cost effective and lead to other environmental benefits such as reduced eutrophication, erosion etc.

The efficiency in utilization of by-products generated in biofuel production has been identified as another parameters affecting the sustainability and land needs of first generation biofuels (Borjesson and Tufvesson, 2009). By-products from biofuel production can be used for various purposes including animal feed, chemicals, fertilizers and feedstock for energy purposes, depending on the feedstock. By using by-products from an existing production plant, raw materials in other production systems can be replaced, and thereby reduce resource input and land use demand. Several studies have estimated the potential effects of displacing feedstock for animal feed (ie. cereals, soya, rapeseed, glycerol) with by-products from biofuel production (Cottrill et al., 2007, Croezen and Brouwer, 2008, Lywood et al., 2009, Ozdemir et al., 2009, Taheripour et al., 2010, Weightman et al., 2010). The results have shown that biofuel crops grown in Europe (i.e. wheat and sugar beet) have the ability to replace between 0.18-0.60 ha per ha of bioethanol feedstock*. Incorporation of the substitution effect from by-products has been proven to be of great importance when modelling land use impacts from expanding biofuel production (Ozdemir et al., 2009, Taheripour et al., 2010).

Although biofuel crops currently occupy a relative small percentage of the total arable land area (see 2.3), substantial additional areas would be required to meet existing biofuel targets. The increased production of cultivated biomass for energy purposes has led to concerns about the risks associated to an increased competition of resources (i.e. land, water etc.) and potential negative effects on food security (Khanna et al., 2009, Pimentel et al., 2008, Sexton et al., 2009). Due to environmental concerns of biofuels, sustainability criteria for production of biofuels has been introduced in the US and in the EU (Harvey and Pilgrim, 2011) regarding reduction thresholds for greenhouse gas emissions. In the EU legislation, criteria for protection of high carbon stock lands and biodiversity have also been set up. Further social sustainability is considered to ensure worker rights and that no child labour occurs in the biofuel production chain. However, the issue of biofuel threatening food security is so far not addressed in legislation.

* Weightman et al. (2010) suggest that by-products generated from one million tonnes of wheat produced in Europe (corresponding to 0.27 Mha assuming yields of 3.7 ton/ha (FAOSTAT 2011), could substitute approximately 0.05 Mha of crop-land for soy production in South America. By-products from 1 ha of sugar beets and wheat (0.06:0.94) are further stressed to be able to replace 0.42 ha of soya land and 0.18 ha crop-land for wheat production.

3.4 Additional challenges

3.4.1 Land degradation

Loss of land due to unsustainable land use practice is an additional cause for increased land use pressure. Land degradation, defined as a long-term decline in ecosystem function and productivity (Bai et al., 2008), negatively affect environmental systems through various types of management practices such as deforestation, over-grazing and over-intensive cropping. It has been estimated that globally 2-5 million hectares of land is lost every year due to land degradation. This can be compared with the expansion of urban areas equivalent to approximately 2 million hectares of land per year (see 2.1.3). Satellite measurements further show that there has been a decline in primary productivity across 12 % of the global land area between 1981 and 2003 (Nellemann et al., 2009). Others have suggested that three quarters of the global land area are affected by major soil constrains (Bot et al., 2000). The major areas of degraded land are found in developing countries situated in tropical regions (i.e. Africa, Latin America and Asia) (Figure 11) (Nellemann et al., 2009).

Agricultural activity is considered to be the primary cause of land degradation (Geist and Lambin, 2004). The relationship between unsustainable cultivation practise and land degradation can be a viscous circle if intensity is increased to improve yields and the long-term effects will be the opposite. Decreased quality and productivity of existing and potential agriculture areas will result in reduced yields and decreased possibilities of expanding agriculture areas. These consequences can have severe effects on food security, and is thought to affect some 15-20 % of the global population (Bai et al., 2008). Unsustainable land use practise is estimated to result in net losses of cropland productivity corresponding to 0.2 % per year (Nellemann et al., 2009) and affect up to 40 % of global croplands (Wood et al., 2000). In south Asia and Sub-Sahara, pointed out as the regions most affected of soil degradation (Overseas Development Group, University of East Anglia, 2006), one to two fifths of all agricultural land has been degraded during the last several decades (Bai, 2007, Foley et al., 2005). In Africa this has resulted in overall yield reductions in the range of 2-40 % with a mean loss of 8.2 % for the whole continent (Nellemann et al., 2009).

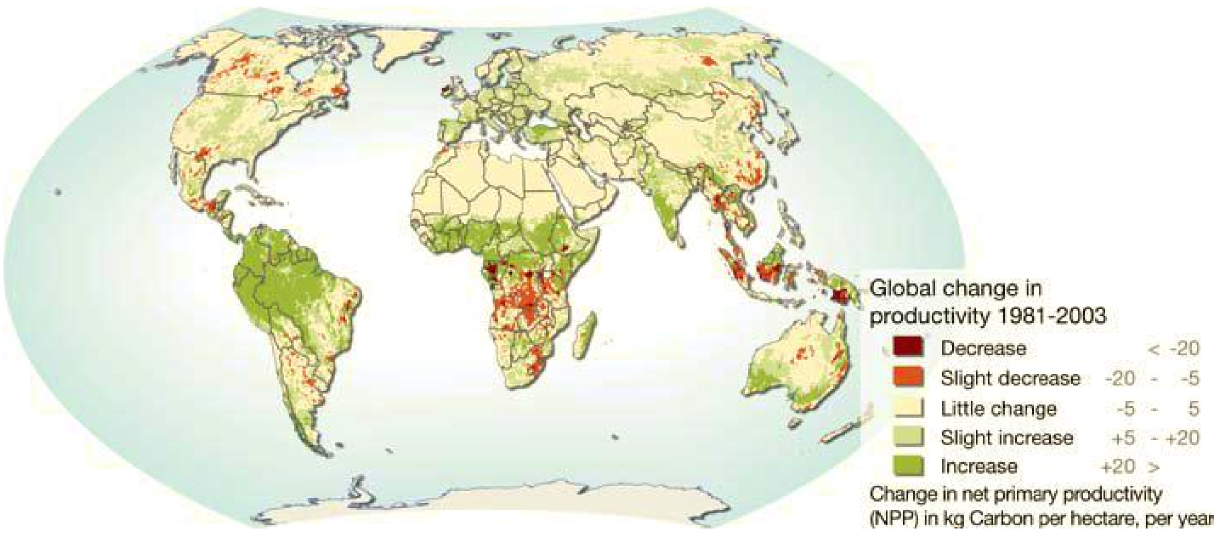


Figure 11. Change in land productivity 1981-2003
Source: (Bai et al., 2008), adapted by (Nellemann et al., 2009)

3.4.2 Climate change

Currently available studies indicate that the overall effect of climate change will reduce global agricultural productivity (Parry, 2007). According to the IPCC Fourth Assessment Report a temperature increase of 1-3 °C will benefit crop productivity in mid and high latitudes, whereas higher temperatures will result in reduced productivity (IPPC, 2007). In agriculture areas at lower latitudes, which are believed to be more vulnerable to climate change, even smaller temperature increases in the range of 1-2 °C is expected to negatively affect crop productivity (Easterling et al., 2007). Positive effects of climate change on agriculture include elevated CO_2 concentrations, increased temperatures and longer growing seasons in higher latitudes. Suggested negative effects associated with climate change are higher temperatures which may increase the risk for drought and reduce the length of the growing season, a possible increase in frequency and severity of extreme weather conditions, increased risk for pest and pathogen outbreaks, and increased risk for water shortage (Easterling et al., 2007, Parry, 2007, Tubiello and Fischer, 2007).

Climate change is expected to above all reduce the cultivation potential in developing countries in the southern hemisphere (Figure 12). This means that the effect of climate change most likely will aggravate inequalities in food production between poor and rich countries (Parry, 2007). In many developing countries yields are estimated to be reduced by about 15-35 % if temperature increases by 3-4º C (Stern, 2006). The worst affected region is believed to be Sub-Saharan Africa (Easterling et al., 2007). Projections indicate that agricultural potential in several African countries could be reduced by as much as 60 % by 2080 (Cline, 2007). Poor people living in rural areas are often highly dependent on ecosystem services and agriculture and are therefore more vulnerable to potential negative effects related to climate change. Lack of capital for adaptation is suggested to be an additional reason why negative effects associated with climate change will hit poor people in developing countries hardest (Tubiello and Fischer, 2007).

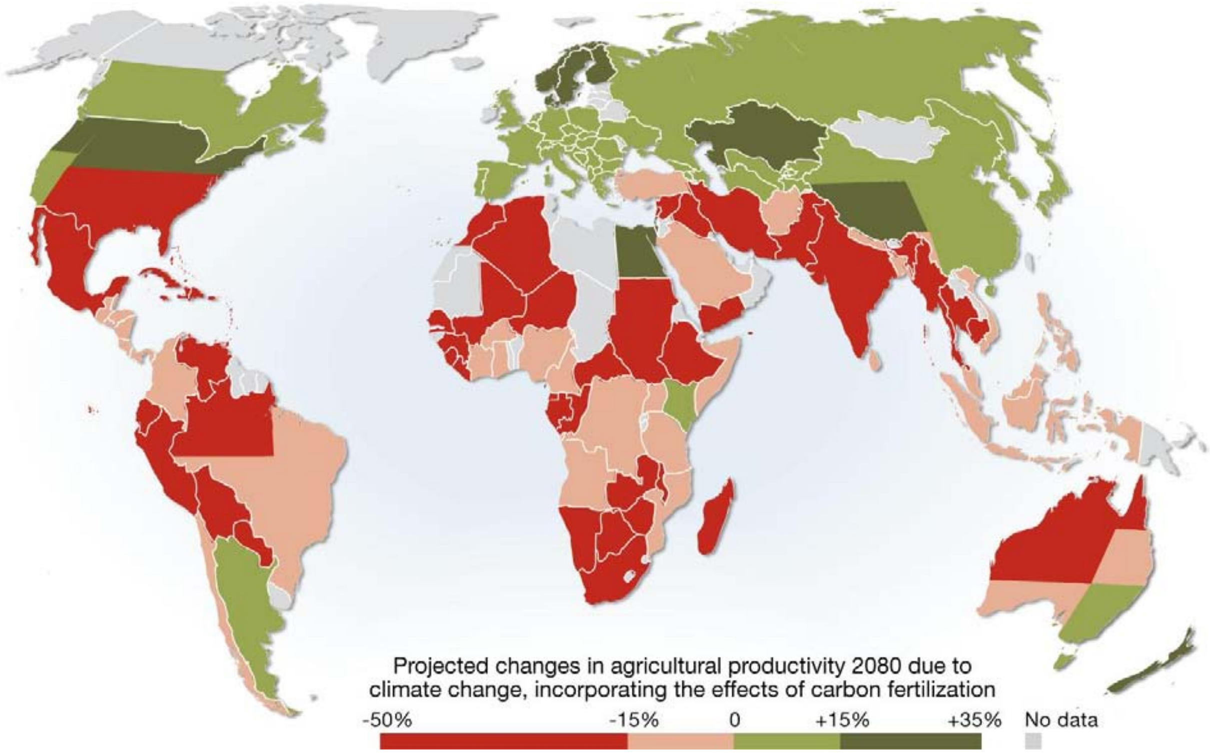


Figure 12. Projected losses in food production due to climate change by 2080
Source: (Cline, 2007) adapted by (Nellemann et al., 2009).

3.5 Summary: Drivers for land use change

Changes in land use are driven and affected by several different factors. In this chapter the following drivers for land use change have been identified and discussed; population growth, increased demand for livestock products, increased demand for bioenergy, land degradation and climate change. Figure 13 shows a schematic diagram of how these drivers together pose a risk for increased future land use conflicts.

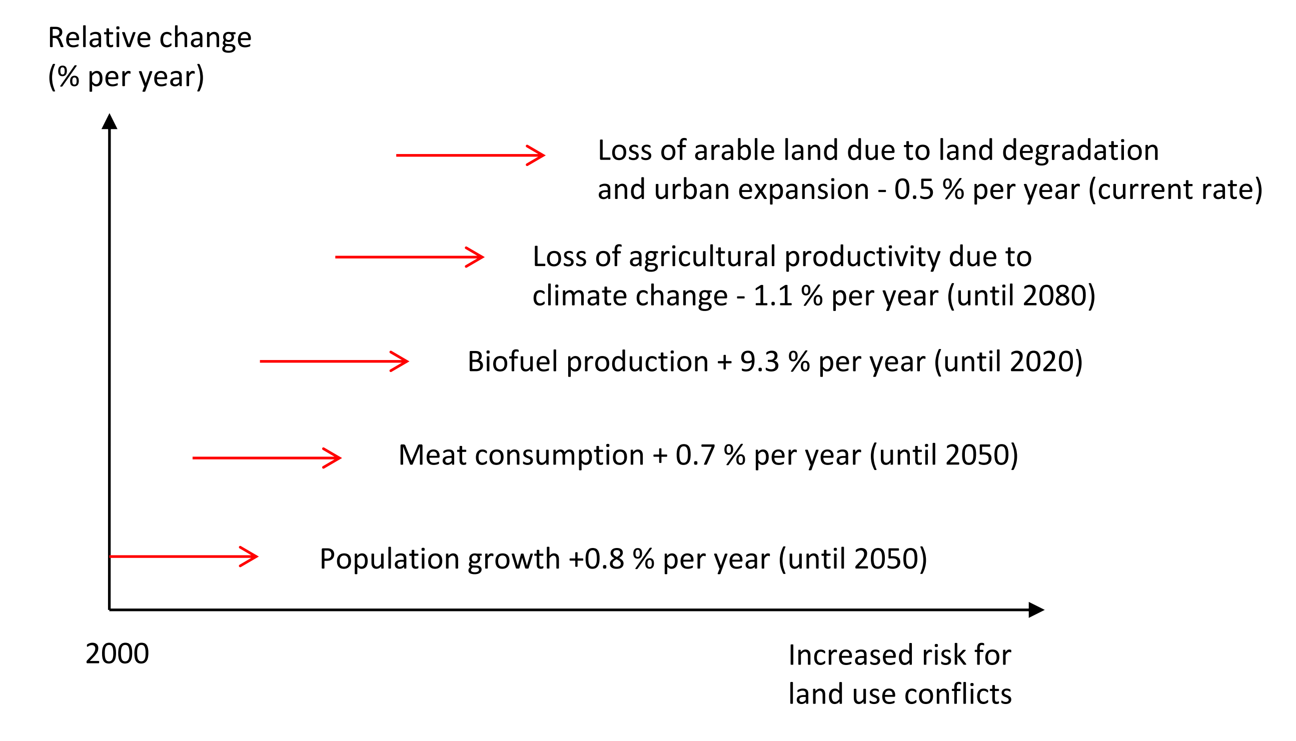
The rate of population growth, along with economic growth is directly decisive for future global demand of food and energy. According to the medium variant of demographic projections the world population is estimated to reach 8.3 billion by 2030 and surpass 9 billion by 2050. The future population growth will almost exclusively take place in the developing world. In total the population in the developing world is expected to increase from 5.6 billion people in 2009 to 7.9 billion in 2050. The biggest population growth is projected in Asia whereas the highest population growth rate is expected in Africa.

During the past fifty years global meat consumption has increased fourfold. The increased consumption of animal products in the industrial countries begun to stagnate but during the last decades a strong trend of increased consumption of livestock products has instead been seen in the developing countries. According to FAO, daily per capita consumption of meat in 2000 was 330 grams in North America, 190 grams in Europe and South America and 73 and 36 grams in Asia and Sub-Saharan Africa, respectively. FAO projections estimate that the global per capita consumption of meat will continue to rise from 37 kg at present to 52 kg in 2050. Increase in livestock production has been a result of increased number of animals and increased productivity. During the past thirty years the number of chickens in the world grew 2.6 times and the number of pigs and cattle by 18 and 14 %, respectively. Projections have shown that livestock production will continue to grow with 85 % between 2000 and 2030 and double until 2050.

Primary solid biomass, representing approximately 99 % of all used bioenergy, covered around 10 % of the total world energy use in 2005. In the developing world the use of solid biomass is dominating whereas the demand for liquid biofuels is increasing in the developed world. The use of biofuels from crops has been identified as a possible way of reducing climate impact from transportation fuels but could also increase the risk for competition of resources and have negative effects on food security. Bioethanol and biodiesel production primarily made from maize, sugar cane and vegetable oils are the dominating biofuels markets. During the last ten years production of ethanol and biodiesel has grown steadily, with a 30 and 40 % increase seen in the respective sector only between 2007 and 2009. Due to rising oil prices and government support the growth in production of bioenergy is expected to continue. Projections estimate that global biofuel use will increase more than four-fold between 2008 and 2035, resulting in an increased share of road fuel supply from 3 to 8 %.

Loss of land due to unsustainable land use practice is an additional cause for increased land use pressure. It has been estimated that globally 2-5 million hectares of land is lost every year due to long-term decline in ecosystem function and productivity (i.e. land degradation). This can be compared with the expansion of urban areas equivalent to approximately 2 million hectares of land per year. The major areas of degraded land are found in developing countries situated in tropical regions. Unsustainable land use practise is estimated to result in net losses of cropland productivity corresponding to 0.2 % per year and affect up to 40 % of global croplands. Decreased quality and productivity of existing and potential agriculture areas will result in reduced yields and decreased possibilities of expanding agriculture areas.

Currently available studies indicate that the overall effect of climate change will reduce global agricultural productivity. Climate change is expected to above all reduce cultivation potential in developing countries in the southern hemisphere. In many developing countries yields are estimated to be reduced by about 15-35 % if temperature increases by 3-4º C. The worst affected region is believed to be Sub-Saharan Africa where agricultural potential could be reduced by as much as 60 % by 2080.



Relative changes are rough estimates based on data for year 2000 and future projections. *Biofuels compared to 2007. Used units for calculations: Loss of arable land: global loss of arable land (in hectares), agricultural productivity: agricultural output potential in worst affected areas, biofuel production: global production of ethanol and biodiesel (in litres), meat consumption: global per capita consumption of meat (in kilograms), population growth: global increase in population. Data are based on references in chapter 3.

Figure 13. Trends of identified drivers for land use change, expressed as relative change per year

4. PREDICTION OF FUTURE LAND USE CHANGE

As described in chapter 1, 2 and 3 growing demand for food, feed and biofuels has resulted in increased competition for land. The impact of climate change and land degradation is uncertain but will most probably reduce availability of areas suitable for agriculture, and thereby put additional pressure on land in the future. In chapter 4 existing predictions of future land use change will be presented (4.1). The presentation of results from these future predictions is followed by a general discussion about uncertainties and difficulties relating to this type of prospective studies (4.2).

4.1 Future land use change

Several studies have tried to predict future land use change by combining the effect of different influencing parameters in complex models. To predict how future demand for food, feed and biofuel will affect the distribution of land is however very difficult as this kind of research is relying on several uncertain assumptions. There are essentially two different ways of presenting results in scenario analysis. Either prospective results are compared with the corresponding situation in a specific year chosen as baseline, or different scenarios can be compared with a reference scenario showing results for the same year.

Scenarios are generally based on a reference scenario that show the result of the combined simulated effect of major socio-economic drivers such as population growth, demographic changes, economic growth, increased productivity, international trade and demand for agriculture products. A reference scenario is usually designed to simulate how the future situation would look like if current trends were extrapolated. The reference projection can further be modified into different scenarios by including the effect of different influencing factors such as changes in political agenda or external factors such as a changed climate.

The fact that many studies are limited to focus on one dimension of a problem, sometimes makes it difficult to compare results from different scenario studies. Many scenario analysis use land use projections from FAO as a reference scenario to compare their results with. According to FAO projections a net expansion of arable land in the magnitude of 120 million hectares, is estimated in the developing countries between 2005/07 and 2050. The greatest share of expansion is expected to take place in sub-Saharan Africa (64 Mha) and Latin America (52 Mha). In the developed countries agriculture land is projected to continue to decline, releasing approximately 48 million hectares until 2050. On global scale the overall change in arable land is estimated to be a net increase of 70 million hectares until 2050, equivalent to approximately 5 % of current arable land. Based on these projections arable land will occupy around 1670 million hectares, or 12.5 % of the global land surface in 2050 (Table 15) (Bruinsma, 2009).

Table 15. Prediction of total arable land according to FAO projections (Mha)

	2005	2030	2050
sub-Saharan Africa	236	275	300
Latin America	203	234	255
Near East/North Africa	86	84	82
South Africa	206	211	212
East Asia	235	236	237
excl. China	105	109	112
Developing countries	966	1040	1086
excl. China and India	666	740	789
Industrial countries	388	375	364
Transition countries	247	234	223
World	1602	1648	1673

Source: Based on historical data: FAOSTAT, 2009. Adapted from (Bruinsma, 2009).

The FAO projection presented in Table 15 takes into account all knowledge currently available and is designed to reflect the future as it can be expected from today’s knowledge base. This scenario is thus not an extrapolation of current trends but rather a description of a projected development, in which major variables may deviate from their trend path. The projections do not include the effect of an additional demand of agricultural products as a result of increased biofuel production, nor the impact of climate change (Bruinsma, 2009).

In a study by Fischer (2009) baseline land use projections by FAO (2009, 2006b) are complemented to include effects from emerging biofuels development and climate change. There are also studies which have modelled land use effects from other factors such as the development of sustainable farming practise including considerations regarding preservation of biodiversity (European Environment Agency, 2007, Fischer et al., 2010). Several studies have moreover modelled the impact of biofuel targets on land use change (Ahlgren and Börjesson, 2011). In Table 16 a summary of recent prospective studies on land use (arable land) is provided, followed by a short description of the design of modelled scenarios in the mentioned studies. The summary in Table 16 illustrates the variation in design of different modelled scenarios. In section 5.3.3 results from scenario studies with a focus on land use will be further discussed.

Table 16. Summary of prospective studies on land use and description of designed scenarios

Reference	Description	Scenario
		Baseline scenarios
Bruinsma (2003)	Projections for 2015 and 2030. Includes only developing countries. Base year 1997/99.	Baseline scenario designed to reflect the future as it can be expected, based on the knowledge at the time. Do not account for additional demand of land needed in biofuel production or land use change due to climate change.
Bruinsma (2009)	Projections for 2030 and 2050. Global perspective. Base year 2005/2007.	Baseline scenario designed to reflect the future as it can be expected, based on the knowledge at the time. Do not account for additional demand of land needed in biofuel production or land use change due to climate change.
		Biofuel scenarios
Fischer (2009)	Projections for 2020, 2030 and 2050. Global perspective. Results presented as the difference between modelled scenarios and a baseline reference scenario.	*WEO-V1*: Transport energy demand according to International Energy Agency (IEA) in its WEO 2008 Reference scenario. Second-generation conversion technologies become commercially available after 2015. *WEO-V2*: Transport energy demand according to IEA in its WEO 2008 Reference scenario. All biofuel production is based on first-generation feedstock until 2030. *TAR-V1*: Transport energy demand according to IEA in its WEO 2008 Reference scenario. Biofuel targets are implemented in major developed and developing countries by 2020. *TAR-V3*: Transport energy demand according to IEA in its WEO 2008 Reference scenario. Biofuel targets are implemented in major developed and developing countries by 2020. One third and half of the biofuel use in developed countries come from second-generation technologies, in 2020 and 2030 respectively.
		Climate change scenarios
Fischer (2009)	Projections for 2020s, 2050s and 2080s. Global perspective. Results presented as the difference between modelled scenarios and a baseline reference scenario.	Three climate change scenarios based on likely future temperatures, rainfall, incoming sun light, etc. according to projections of future CO_2 levels. Scenarios with and without consideration to the CO_2-fertilization effect.

Fischer (2005)	Projections up to 2080. Global perspective. Results presented as the difference between modelled scenarios and a baseline reference scenario.	Five climate change scenarios based on the IPCC-SRES scenarios with different levels of climate sensitivity. Climate change scenarios were combined with four different socio-economic scenarios as specified in the IPCC special report on emissions scenarios (SRES).
		Combined scenarios
Fischer (2009)	Projections for 2020, 2030, 2050 and 2080. Global perspective. Results presented as the difference between modelled scenarios and a baseline reference scenario.	Combined impact of climate change and expansion of biofuel production. Modelled biofuel and climate change scenarios as described previously.
European Environment Agency (2007)	Projections for 2035. Includes EU-25 + Norway and Switzerland. Base year 2005.	*Great Escape*: Intensified production but total agriculture diminishes. Many nature reserves and extensive farmland are lost. Low environmental awareness and increasing environmental pressure. Unchanged demand for bioenergy. *Evolved society:* High environmental pressure and increased environmental awareness. Farming is high-tech and increasingly organic. Decreased farming intensity and extensive farmland conserved. Increased support for bioenergy. *Clustered Networks*: Agriculture marginalises. Agriculture land strongly decreases. Increased environmental awareness. *Lettuce surprise*: New crop varieties are invented. Agriculture is high-tech, clean and small-scale. Due to increased productivity, cropland decreases strongly. Growing environmental awareness. *Big crisis:* High environmental pressure and increased environmental awareness. Agriculture intensification is largely reversed after 2015. Cropland and grassland decrease moderately.
Fischer (2010)	Projections for 2030. Includes EU 27 + Ukraine. Results presented as the difference between modelled scenarios and a baseline reference scenario.	*Environment oriented scenario:* Growing emphasis on sustainable farming practise and biodiversity. Larger areas for organic farming and marginal farmland preserved for extensive farming and nature conservation. *Energy oriented scenario:* Surplus pasture land for growing herbaceous energy crops. Zero-tillage crop cultivation techniques are developed for cultivation of energy grasses. Available surplus pasture land not required for grazing animals is constrained by nature conservation concerns.

4.2 Reliability of scenario analysis

4.2.1 Uncertainties and assumptions

Scenario analysis can either be designed to predict the most likely future situation, or describe various possible futures that could become a reality under different circumstances. Irrespective of the objective, scenario analysis predicting future land use change is challenged by various uncertainty factors and limitations.

In land use projections by FAO (Table 15) (Bruinsma, 2003, Bruinsma, 2009) data from the medium variant of demographic projections of the United Nations Population Division are used for projections of population growth. As described in section 3.1 there is also a low and high variant which estimate the global population to be in the range between 8 and 10.5 billion people in 2050 (United Nations, 2009). Several used data in projections of land use change are in the same way based on mean values without taking into account large standard deviations existing in the original results. When different modelling frameworks such as agro-ecological zoning information, demographics, socio-economic drivers and climate scenarios, with their respective assumptions and limitations, are combined to predict future land use change this will lead to large uncertainties in the final results.

As mentioned before, many scenario analyses are limited to focus on one dimension of a problem. This means that the combined effect of future agriculture constrains such as land degradation, water shortage and climate change is hard to estimate. Other difficulties contributing to the complexity of predicting future land use change are limitations in reliability of land use data, discussed in 2.2, and the impossibility to predict system changes or crisis such as war or natural disasters.

4.2.2 Comparison of land use change predictions

The design of each studied scenario will be crucial for the final results of land use predictions. In this section land use predictions from five different scenarios with different designs and assumptions are compared. The compared scenarios are; FAO-REF-00, a reference projection by IIASA where no additional demand for biofuel production is assumed and where current (2008 as base year) climate conditions prevail (Fischer, 2009), the projections towards 2030/2050, developed by FAO (Table 15) (Bruinsma, 2009), designed to reflect the future as it can be expected from today´s knowledge base without taking into account additional demand for biofuel or effects from climate change, a climate change scenario based on FAO-REF-00 which models the effect of different scenarios of climate change according to the IPCC SRES A2 scenario (including the effect on crop yields, extent of land with cultivation potential and the number and type of crop combination possible to cultivate) (Fischer, 2009), a biofuel scenario based on FAO-REF-00 which models the effect of increasing demand for biofuel based on the World Energy Outlook reference scenario (International Energy Agency, 2008) and different shares of biofuels in final energy consumption (Fischer, 2009) and finally a scenario of the combined effect of climate change and increased demand for biofuels, based on the previous described scenarios (Fischer, 2009). The predictions of global area occupied by cultivated land in 2030 and 2050, for each scenario, are summarized in Table 17.

Table 17. Predictions of global cultivated area in 2030 and 2050 (Mha)

	2030	2050
Bruinsma (2009)*	1648	1673
FAO-REF-00**	1676	1727
Climate change scenarios**	1675-1681	1724-1735
Combined effect of climate change and biofuel**	1693-1725	1747-1785

* Reference scenario from FAO (see Table 15) **Scenario results from (Fischer, 2009).

The comparison show how the results vary depending on the design and assumptions in the respective scenario. Although the projections by Bruinsma (2009) and FAO-REF-00 used similar assumptions (no additional demand for biofuel, no effect of climate change) in their design, Bruinsma (2009) projected a smaller expansion of cultivated land compared to FAO-REF-00. The global cultivated area in 2030 projected in FAO-REF-00 is rather in line with the projections for 2050 by Bruinsma (2009), meaning that there is a 28-54 million hectares difference in the projections between the two scenarios

Climate change had a rather small effect (-3/+8 Mha net change in 2050, compared to FAO-REF-00) on expansion of cultivated land towards 2030 and 2050, according to the climate change scenario. The impact of climate change was in this study more significant in the predictions for 2080. The net change in cultivated land relative to FAO-REF-00 was +10/+26 million hectares, depending on the chosen assumptions. Some of the scenarios for 2030 and 2050 predicted a net decrease in global cultivated land, which mainly was a consequence of increased crop yields due to the effect of increased CO_2 fertilization. The negative effect of climate change on crop yields, which increased gradually over time, however exceeded the positive effects on crop yields and resulted in a net expansion of cultivated land in most scenarios. When interpreting the results from the climate change scenarios it should be noted that these scenarios assume full agronomic crop adaptation and do not account for impacts of possible increased climatic variability. The results further predict adverse effects in many developing regions such as in South Asia and Sub-Saharan Africa, where significant reductions in crop production were projected in all climate change scenarios.

The size of areas occupied by biofuel feed crops were highly dependent on the time second generation biofuels will become commercially available as well as on the deployment of new techniques. In this study the biofuel scenarios were based on the energy demand and biofuel use projected by International Energy Agency (IEA) (2008) in its WEO 2008 Reference Scenario, which have estimated the final biofuel consumption to approximately 5.2 and 8.8 EJ, in 2030 and 2050 respectively. The projections correspond to an increase of 2.4 and 4.4 times compared to current biofuel consumption. In some of the scenarios (TAR scenarios) the final consumption of biofuels was increased to 12.4 EJ and 17.8 EJ respectively in 2030 and 2050, an increase about twice as high as in the WEO scenarios and 6-8 times as high as the consumption of today. How much production of biofuel will increase in the coming decades will be highly dependent on political goals and policy measures within this field (e.g. see Table 14), in addition to increases in oil prices. It should further be noted, as mentioned in the study by Fischer (2009) that few countries have announced biofuel targets beyond 2020, why predictions of land use change for 2030 and 2050 must be interpreted with caution.

Increased biofuel demand is predicted to have the highest impact on land use in the period up to 2030, when second generations techniques are still new and/or under development. For climate change the opposite effect is expected, as the CO_2 fertilization effect could delay the negative impact on crop yields in a short term perspective while the overall negative effects of climate change are expected to get worse over time (Fischer, 2009).

The predictions of arable land in the scenarios for 2050, shown in Table 17, vary from 1673 to 1785 million hectares. Other projections have presented results with even larger variations. Predictions from the OECD Environmental Outlook and IAASTD have for example estimated global arable land areas to occupy around 1800 million hectares already by 2020 (Croezen et al., 2010). The great variations in results illustrate the high degree of uncertainty existing in scenario analysis and how different assumptions can affect the final outcome.

4.2.3 Comparison of old projections with actual outcome

One way to evaluate the reliability of scenario analysis is to compare old projections with the actual outcome in a projected year. Previous projection studies developed by FAO include agricultural outlooks towards 2000 (Alexandratos, 1988) and 2010 (Alexandratos, 1995). As mentioned earlier the FAO medium variant projections are based on the medium variant population projections developed by the United Nations Population Division. As population growth is directly decisive for future demand of agriculture products, and thereby future land use change, the accuracy of populations projections will have a large impact on how well land use projections agree with the actual outcome. In the 1995-study (Alexandratos) the world population was projected at 7.2 billion for 2010, in the coming FAO projection study by Bruinsma (2003) the projections of the world population had decreased to 6.8 billion in 2010, which further can be compared to the world population estimations in mid-2010 at 6.9 billion (Population Reference Bureau, 2010). The difference of 100-300 million people between the projections and the actual estimate in 2010 will affect land use predictions based on these numbers. Similarly the population in sub-Saharan Africa was projected to reach 915 million by 2010 in the 1995-study (Alexandratos) and 780 million in the 2003-study (Bruinsma). The actual population in Sub-Saharan Africa was estimated to 865 million in mid-2010 (Population Reference Bureau, 2010). Other examples of data that have been revised in later projection studies are data for Gross Domestic Product and data for food production, demand and per capita consumption (Bruinsma, 2003).

Land use projections by Alexandratos (1995) predicted that land in crop production (arable land and permanent crops) in the developing countries, excluding China, would expand by about 90 million hectares from 769 million hectares in 1988/90 to 850 million hectares in 2010. In the FAO report by Bruinsma (2003) total arable land in developing countries excluding China was reported to occupy an area of 822 million hectares which seem to correspond quit well with the earlier prediction when areas cultivated with permanent crops are added.

4.2.4 Value and use of scenario analysis

Although scenario analysis is challenged by several limitations that affect the reliability of the results, it is a frequently used tool to predict future development. Scenario analysis can be used to predict trends and test the effect of different strategies and policy options, why it is perceived as a useful tool to support decision making in international organizations, companies and governments worldwide (European Environment Agency, 2007).

As the future is unknown and different future developments are possible it is unfeasible to make accurate predictions. The main purpose of land use predictions are therefore rarely to predict exact values but rather to demonstrate the magnitude of change that can be expected. Using information from scenario analysis can in this way help to give a better understanding of factors and trends that will have a major impact on future land use change, identify effective strategies to minimize land use conflicts and set priority for actions to be taken.

4.3 Summary: Prediction of land use change

Several studies have tried to predict future land use change by combining the effect of different influencing parameters in complex models. Scenarios are generally based on a reference projection that show the result of the combined effect of major socio-economic drivers such as population growth, demographic changes, economic growth, increased productivity, international trade and demand for agriculture products. A reference projection can further be modified into different scenarios by including the effect of different influencing factors such as changes in political agenda or external factors such as a changed climate.

Reference projections of future land use change by FAO estimate a net expansion of arable land in the magnitude of 70 million hectares, or 5 % until 2050 compared to the arable area in 2000. Based on these projections global arable land will occupy around 1670 million hectares, or 12.5 % of the global land surface in 2050. The greatest share of expansion of arable land is expected to take place in sub-Saharan Africa and in Latin America. In total the net expansion of arable land between 2005/7 and 2050 is projected to be about 120 million hectares in the developing countries, whereas around 50 million hectares of arable land is expected to be released in the developed world.

Predictions of future land use change are relying on several uncertain assumptions which will affect the reliability of the final results. Limitations in reliability of land use data and the impossibility to predict system changes or crisis, such as war or natural disasters, are examples of uncertainties contributing to the complexity of predicting future land use change. Many scenario analysis are further limited to focus on one dimension of a problem why the combined effect of future agriculture constrains (i.e. land degradation, water shortage, climate change) is hard to estimate. By comparing results from scenario analysis with different designs and assumptions the variation in predicted outcome can be illustrated. In this section land use predictions from four different scenarios (two reference scenarios, a climate change scenario and a combined climate change and biofuel scenario) were compared. The predictions of global cultivated area under the period up to 2050 varied between 1670 and 1800 million hectares, corresponding to an expansion of 9-17 % compared to the cultivated area in 2000 (Figure 14).

Another way to evaluate the reliability of scenario analysis is to compare old projections with the actual outcome in a projected year. In previous predictions by FAO the world population was projected at 7.2 billion for 2010, in a later FAO projection study the world population for 2010 was estimated at 6.8 billion, which can be compared to the world population estimations in mid-2010 at 6.9 billion. The difference of 100-300 million people between the projections and the actual estimate in 2010 will further affect land use predictions based on these numbers. Other examples of data that have been revised in later projection studies are data for Gross Domestic Product and data for food production, demand and per capita consumption.

Although scenario analysis is challenged by several limitations that affect the reliability of the results, it is a frequently used tool to predict future development and support decision making. Using information from scenario analysis can in this way help to give a better understanding of factors and trends that will have a major impact on future land use change, identify effective strategies to minimize land use conflicts and set priority for actions to be taken.

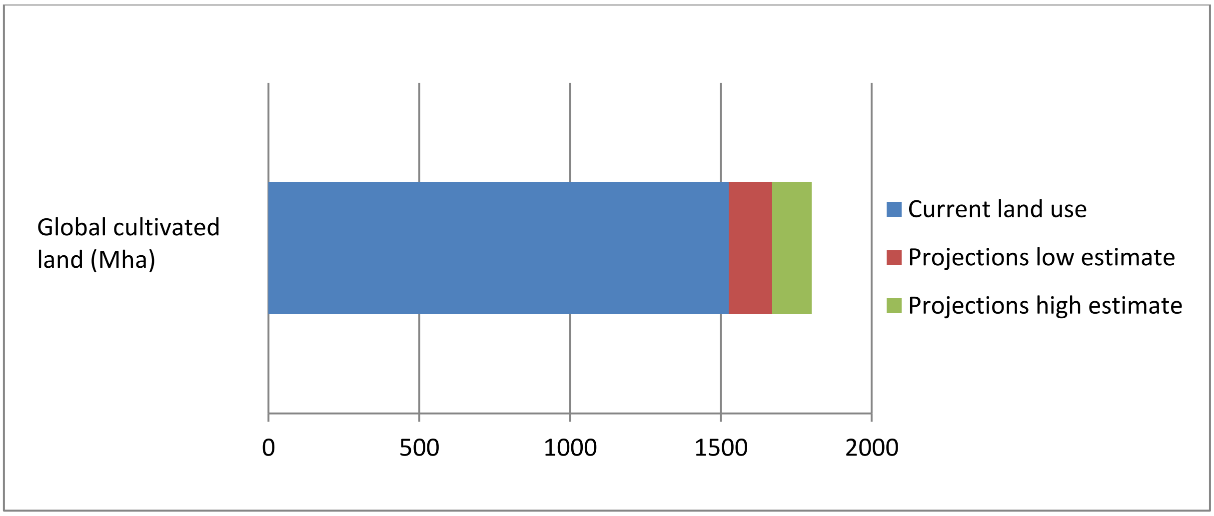


Figure 14. Global cultivated land in Mha, based on current land use (2008) and projections for land use change during the period up to 2050.
Data are based on references in chapter 4.

5. OPPORTUNITIES FOR MINIMIZING LAND USE CONFLICTS

Despite the uncertainties in predictions of future land use demands, discussed in chapter 4, it is obvious that there is a need to develop strategies to meet potential risks of increased land use conflicts. In chapter 5 the potential of four identified opportunities for minimizing land use conflicts will be discussed. These opportunities have been identified as the most important for future land use changes. The opportunities are; increased land in cultivation (5.1), increased productivity (5.2), dietary change (5.3) and minimizing food losses and waste (5.4). The opportunity to reduce land use pressure by reducing the demand for non-food agricultural products will not be investigated. Instead the possibilities of securing global demand for food at the same time as part of global agriculture areas are used for other purposes, such as for production of biofuels, will be explored.

5.1 Increased land in cultivation

Several studies have projected that an increase in agriculture land will take place to meet the growing demand for agriculture products (see chapter 4). The possibility to increase land for cultivation in a specific region depend on given conditions of soil quality and climate but also on the access of available resources and the agricultural profitability. With the assistance of irrigation and artificial fertilizers also land with less favourable conditions can be cultivated. In this section the opportunity of expanding arable land, in order to increase future agricultural output, will be discussed from different perspectives.

Potential arable land is a term commonly used to define land areas suitable for cultivation and refers to all types of land with crop production potential (Bruinsma, 2003). A wide range of studies has investigated the available cultivable land with varying results (Cohen, 1995). According to FAO approximately 30 % of the world surface (4200 Mha) is to some degree suitable for rainfed agriculture (Table 18) (Bruinsma, 2003). Just over a third of the total potential arable land that is suitable for rainfed cultivation is already used for cropping (1534 Mha), which means that there is a theoretical capacity to expand current rainfed crop-land with up to 2700 million hectares. In addition there is a more limited potential to expand irrigated crop-land on land not suited for rainfed cultivation. In the developing world, where most of the expansion of arable land is projected to take place, the remaining land area (not currently in use for cultivation) with rainfed crop production potential has been estimated to 1800 million hectares. Out of these 1800 million hectares 90 % are found in Latin America and sub-Saharan Africa (Bruinsma, 2003). In North Asia, Asia and the Pacific, North America and Europe 54-64 % of the potential rainfed arable land is already in use which means that the possibility for agricultural expansion in these regions is limited (Bot et al., 2000). In other parts of the world such as in Japan, South Asia and the Near East/North Africa there is small or no possibilities to expand agriculture areas (Figure 15) (Bruinsma, 2003).

Table 18. Distribution of land with rainfed crop potential by region

	Total land area (Mha)	Theoretical potential arable land* (Mha)	Extent of potential arable land out of total land (%)
World	13400	4188	31
Developing countries	7302	2782	38
Industrial counties	3248	874	27
Transition countries	2305	497	22
Sub-Saharan Africa	2287	1031	45
Near East/North Africa	1158	99	9
Latin America and Caribbean	2035	1066	52
South Asia	421	220	52

*Includes marginal and moderately suitable land. Source: (Bruinsma, 2003)

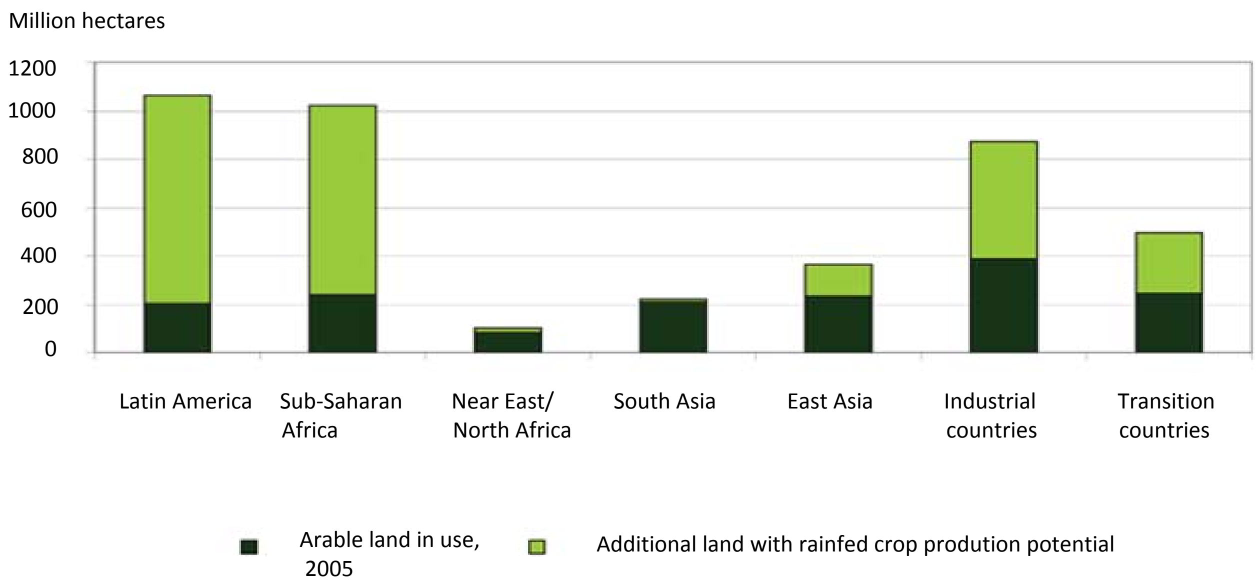


Figure 15. Distribution of land with rainfed crop potential by region
Source: (Bruinsma, 2009). Adapted from (FAO, 2009a)

All theoretical potential arable land is in practise not suitable for cultivation. Any land that can support a single crop at a minimum yield level is defined as potential arable land, why also land with low quality is included (Bruinsma, 2003). Potential arable land also includes land areas already occupied by forest, pasture land and urban areas. Alexandratos (1995) estimated that almost half of the rainfed potential arable land is covered by forest and that another 3 % is occupied by human settlement. Smeets et al. (2007) further estimated that 36 % of the land suitable for crop production is covered by permanent pastures. An additional reason why part of the theoretical potential arable land could not be used in practise is that part of the land suitable for crop production suffer from constrains such as ecological fragility or lack of infrastructure (Bruinsma, 2003). Fischer (2002) showed that 70 % of the rainfed potential arable land in Latin America and sub-Saharan Africa suffered from some grade of soil or terrain constraints. When these aspects are considered the actual land areas available for expansion of arable land are smaller than in earlier reported data. The suggested areas of potential arable land have further been criticized to be overestimated, in particular in the developing countries (Young, 1999).

A conclusion from above is that previous studies indicate that remaining land areas suitable for crop production to a large extent is covered by forest or pastures, particularly in the developing regions. To expand crop areas, options such as cultivation on abandoned arable land, pasture land or marginal land, thus has to be considered. The use of terms such as abandoned and marginal land in the literature can easily create confusion as clear and consistent definitions are missing. The fact box below describes different types of land that usually fall under one of the two categories. Abandoned agriculture land, pasture and marginal land does in practise often overlap. In the following sections the possibilities of expanding arable land by redistributing existing agriculture land will be briefly discussed.

Box 3. Definition of abandoned and marginal agriculture land

Abandoned agriculture land: Agriculture land can be abandoned due to loss of quality of land, economic reasons and/or decreased demand for agriculture land. Abandoned agriculture land is often a consequence of increased yields and unchanged or decreased demand for agriculture products in industrialized countries, resulting in reduced profitability for farmers. In poor regions lack of economy and resources are the main reasons for why agriculture land is abandoned. Generally there is a distinction between temporary fallow land (less than five years) which is incorporated into the definition of arable land and permanent fallow land (more than five years) that falls outside the definition of arable land (FAO, 2009b).

Marginal agriculture land: Land with poor ecological conditions. The term can refer to degraded land or land that for other reasons are less suited for crop production, such as chemically polluted land or land that remains uncultivated for economic reasons (Bustamante et al., 2009, Croezen et al., 2010).

5.1.1 Cultivation on abandoned arable land

Estimates of global abandoned agriculture areas (arable and pasture areas), after excluding areas converted into crops, forest and urban areas, range from 386 – 580 million hectares

(Berndes et al., 2003, Campbell et al., 2008, Field et al., 2008, Hoogwijk et al., 2003, Siebert et al., 2010, Tilman et al., 2006). Projections have shown that areas in the magnitude of 3.5-25 million hectares will be abandoned in the EU until 2030 (Croezen et al., 2010). FAO has further estimated that 13 million hectares of the current idle land in the former Soviet Union could be cultivated with no major environmental cost (FAO, 2008a). Including Ukraine, another projection suggested that between 44 and 53 million hectares will become available for agriculture in Europe, by 2030 (Harvey and Pilgrim, 2011).

Mean annual production rates on abandoned lands has been estimated between 1 – 10 tonnes of above ground biomass (AGB) per hectare (Berndes et al., 2003,Campbell et al., 2008, Hoogwijk et al., 2003, Tilman et al., 2006). This means that about 400 - 5800 million tonnes of AGB could be produced from existing abandoned agriculture areas (including former pasture areas), corresponding to around 10-100 EJ which can be compared to current use of solid biomass estimated to 45 EJ (International Energy Agency, 2006).

To bring abandoned arable land into cultivation and reduce areas of fallow land can depending on the specific situation result in either positive or negative local environmental consequences.

5.1.2 Cultivation on pasture land

About one quarter of the global land surface is covered by pasture land (data for 2008) (FAO STAT 2010) and approximately one third of all arable land is used for feed crop production (Steinfeld et al., 2006). This means that there is a large theoretical potential of converting land used for livestock production into crop-land for direct human consumption and biomass production for other purposes. The trend towards a more intensive animal production with higher productivity and a greater use of mixed (combination of pastoral and land less intensive production systems) and "land less" (no grazing) farming systems has already decreased grazing areas in many industrialized countries (ie. in Europe, North America and Oceania) (FAO, 2009b). Also the transition towards an increased demand for farm land efficient livestock such as poultry and pigs contribute to less pressure on pasture areas. In other regions of the world (ie. in Latin America, the Baltic States and CIS, Africa and developing Asia) pasture areas are expanding (FAO, 2009b) and are projected to be stable or continue to increase over the coming next decades (Kemp-Benedict et al., 2002). Smeets et al. (2007) has estimated that a transition towards mixed and non-grazing production systems could release around 1200 and 3700 million hectares of agriculture land respectively, between 1998 and 2050. Future demand for pasture land will among other things depend on the development of animal production systems and dietary preferences (discussed in section 5.2 and 5.3).

All pasture areas are however not suitable for cultivation due to the variation in land quality and other constrains. Smeets et al. (2007) has estimated that about 1370 million hectares, or about 36 % of the total land used for livestock production (arable and pasture land) was suitable for cultivation, in 1998. This indicates that there is a substantial theoretical potential of increasing arable land areas at expense of current pasture areas.

It must be born in mind however that grazing of land contributes with several positive effects both in an ecological and social context. First of all grazing of land can be seen as a resource efficient way of feeding ruminants as no (or less) input of fertilizers and fossil fuels during farming is needed. Pasture land can also contribute to increased biodiversity by keeping landscapes open and act as a sink for carbon, if the number of ruminants does not exceed the ecological capacity when it instead can be a cause of land degradation and soil carbon losses (Garnett, 2009). This would mean that carbon sequestration in pastures could compensate for some of the climate impact related to production of ruminant meat and that grazing animals to some extent are essential for conserving high biodiversity on grassland (Soussana et al., 2007, Stahlberg, 2010). Finally the welfare of many, in particular poor, communities are highly dependent on meat, dairy products and leather from grazing ruminants (Bot et al., 2000).

5.1.3 Cultivation on marginal land

It is not certain how much marginal land exists with crop production potential. To some extent degraded land overlap with abandoned arable land, previously discussed, as former crop-land makes up a large part of existing degraded land areas. Cultivation on marginal land has been suggested to be a sustainable alternative for expansion of biofuel production and cultivation of perennial crops. The low productivity on marginal lands means that the areas often are of low competition for other usages such as food and feed crop production. Crops with low demands for water and nutrients (ie. perennial grasses or trees) could thereby be produced on this land without increasing the overall pressure on existing crop-land (Bustamante et al., 2009).

The global extent of marginal and abandoned cropland with rainfed agricultural production capacity has been estimated to be in the range of 300-700 million hectares (Cai et al., 2011, Campbell et al., 2008, Field et al., 2008). Usage of irrigation and fertilizers could improve farming conditions and agricultural output on marginal lands, it is however questionable if this is an option from an economical and environmental point of view. The potential of cultivation on marginal land is still uncertain and in the literature there are both expressions of high expectations, while others mean that it would be an expensive and unlikely option. The ability to cultivate marginal land depends much upon intensified use of inputs and economic support for cultivation on less productive areas (Croezen et al., 2010).

Conversion of land into crop-land involves a risk for carbon leakage and loss of biodiversity. Marginal land however often refers to land with low biological diversity and which store little carbon (Bustamante et al., 2009), which reduces the risk for negative environmental effects. If cultivation of marginal land would lead to increased use of pesticides, fertilizers and irrigation this could however have adverse environmental impacts. On the other hand systems based on perennial crops could be a sustainable option which both could improve biodiversity and have beneficial effects on the ecosystem (Rathmann et al., 2010).

5.2 Increased productivity

Globally, it is argued that there is enough food produced to feed our world (Smil, 2000). Due to a number of factors, including inefficient use of crops for food production, losses and wastage, production of non-food crops and poor distribution of food, still 925 million people in the world lack adequate food for the day (FAO, 2010b). To decrease global food insecurity there is a need for a more efficient use of agricultural crops produced. It is however often also stressed that increased productivity in agriculture is required to feed our growing population. According to FAO´s projections food production must increase with 70 % until 2050 to meet the global demand (FAO, 2009a).

5.2.1 Potential for increased productivity

Historically increased agricultural productivity has mainly occurred as a result of the introduction of new techniques resulting in higher yields. Between 1950 and 2000 the world agriculture production increased threefold at the same time as global farmland increased with less than 25 % (Federico, 2009). Also in the future the majority of the increase in crop production is projected to come from an intensified agriculture production. Ninety percent (80 percent in developing countries) of the increased agricultural output until 2050 has been predicted to come from either higher yields or increased cropping intensity (i.e. increasing multiple cropping and shorter fallow periods). This projection implies expanding irrigated land areas (32 Mha or 11 % increase until 2050) and a continued but decelerating increase in yield of about 0.8 % per year (mean value at global scale) (Bruinsma, 2009).

Existing yield gaps between agro-ecologically attainable and current crop yields in various areas of the world indicate that there is a considerable potential to further increase yields with available technology (Bruinsma, 2009). In many developing and transition countries, and some industrialized countries, wheat yields have been calculated to be between 30-60 % of the attainable yield (Smeets et al., 2007). By increasing yields in crop and livestock production global biomass and food production could increase significantly without expanding agriculture areas. Studies have estimated that increasing yields through advances in technology could increase global crop production with approximately 50 % or more by 2050 without extra demand for land (Jaggard et al., 2010).

The increase in yield seen during the past century has been a result of a substantial intensification of the agriculture sector. During what usually is called “the green revolution”, the use of new crop varieties, chemical fertilizers, pesticides, irrigation and mechanization have made it possible to significantly increase global biomass production. Options of how to enable further increases in crop yields vary between different regions. In some parts of the world, mainly in developing regions, increased intensification in a traditional way could enable further substantial growth in crop and livestock production. Common constrains for such a development are economical limitations, lack of transport and market infrastructure (Godfray et al., 2010a). The constant development of increased knowledge and novel technologies also provide new opportunities of increasing efficiency in agriculture. Advances in gene technology and the introduction of genetically modified crops is only one example of new techniques that has open up the doors for new opportunities including high yielding crops with designed properties and optimized nutritional content.

5.2.2 Environmental impact from intensified agriculture systems

Increased cropping intensities on existing farm land and pasture land could in a way be beneficial from an environmental point of view, as increasing yields theoretically could prevent further deforestation and decrease pressure on land less suited for cultivation, and with high biodiversity (Bruinsma, 2003). The intensification of the agriculture sector could however also lead to negative environmental consequences including loss of soil carbon, eutrophication, fertilizer and pesticide pollution, increased land degradation and not at least loss of biodiversity as a result of unsustainable land use management (Bruinsma, 2003, Matson et al., 1997). To increase productivity and minimize negative environmental consequences there is thus a need for a sustainable agricultural intensification which enables an increase in production of biomass from the same land area while environmental impacts are reduced or kept constant (Godfray et al., 2010a). A sustainable intensification will require substantial improvements in agriculture including management of water, nutrients, energy, mechanization, well planned crop rotation, as well as new innovative technologies. Intensification of the livestock sector has further been questioned from an animal welfare perspective (Cozzi et al., 2009, Meluzzi and Sirri, 2009, Scipioni et al., 2009). Thus the net environmental and ethical consequences of an intensified agriculture production must be analyzed from a broad system perspective.

5.2.3 Alternative production systems

Organic agriculture, which among other things restricts the usage of chemical fertilizers and synthetic pesticides, is one example of a less intensive agriculture system. Lower yields and insufficient quantities of organically acceptable fertilizers on existing farmland are commonly used arguments against organic farming (Badgley et al., 2007). Positive effects from organic farming include limited usage of chemical compounds and farming methods that protect biodiversity and animal welfare. Whereas organic production has been shown to be able to increase agricultural productivity in low income countries, it is often associated with lower yields in industrialized countries where high technology agricultural systems are in use (Neal and Radford, 2008). FAO and the UN promote organic production as an opportunity to reduce poverty and increase food security in poor regions. In their opinion organic agriculture is a preferable option in low income countries as it requires small amounts of external input, in terms of financial input and other resources, and can help to build up natural resources (United Nations, 2008). The question if organic farming can feed the current and future human population has been widely debated. Some studies have shown that organic agriculture has the potential to contribute substantially to global food supply (Badgley et al., 2007, Perfecto and Badgley, 2007, Saunders, 2008) whereas others argue that the potential for organic agriculture to feed the world is exaggerated (Connor, 2008, Gianessi, 2009).

A study performed by the European Environmental Agency (2007) investigated the opportunity to increase production of biomass in Europe in an environmentally compatible manner. The study showed that a combination of increased land areas used for environmentally oriented farming, including organic production, and technological development could increase European production of bioenergy with approximately 50 % in a near future and by 150 % until 2030. The results indicate that environmentally oriented farming systems, where technological development and organic agriculture is combined, could lead to a sustainable intensification and increased productivity both in industrial countries and in the developing world.

5.3 Dietary change

Throughout the world major shifts in dietary patterns are occurring including a nutrition transition from diets primarily based on carbohydrates-rich staple food towards a diet rich in energy dense foodstuff such as vegetable oils, animal products and sugar (Kearney, 2010). Excessive consumption and production of livestock is associated with several negative aspects including the effect on climate impact, public health, land use and food security, why increased demand for meat and dairy products (described in section 3.2) is concerning.

5.3.1 Reasons for dietary change

The climate impact of the animal sector has been increasingly recognized during the past decade and is estimated to account for between 18 and 51 % of global anthropogenic greenhouse gas emissions (Goodland and Anhang, 2009, Steinfeld et al., 2006). Numerous studies have shown that diets rich in meat and dairy products are associated with higher climate impact than plant-based diets (Baroni et al., 2007, Carlsson-Kanyama and Gonzalez, 2009, Marlow et al., 2009, Stehfest et al., 2009). To some extent improvements in production could reduce the environmental impact from the animal sector (Audsley et al., 2010a, Weidema et al., 2008). The total environmental improvement potential for reducing climate impact from the meat and dairy sector has been estimated to be up to 25%. Due to the limited improvement potential of reducing climate impact in agriculture, greenhouse gas emissions from livestock production would remain substantial even if improvements in production were to be implemented successfully (Weidema et al., 2008). Dietary change has therefore been proposed as an additional necessary measure of mitigating greenhouse gas emissions from the food sector (Audsley et al., 2010a, Audsley et al. 2010b, Carlsson-Kanyama and Gonzalez, 2009, Friel et al., 2009, Garnett, 2011, Millward and Garnett, 2010, Stehfest et al., 2009, Weidema et al., 2008, WWF, 2011).

A change towards less meat-oriented diets has further been suggested to have positive effects on public health in regions where high consumption of meat and dairy products may contribute to an excessive intake of energy, cholesterol and saturated fat, which are known risk factors for the metabolic syndrome (Friel et al., 2009, Micha et al., 2010, WHO/FAO, 2003). Red (beef, lamb and pork) and processed meat (bacon, salami, sausages, hot dogs etc.) has moreover been associated with increased risk of cancer, especially colorectal cancer (Ferguson, 2010, Miles, 2008, Sinha et al., 2009) why the World Cancer Research Fund and American Institute for Cancer Research recommend a diet mainly based on food of plant origin and limited intake of red and processed meat (World Cancer Research Fund / American Institute for Cancer Research, 2009, World Cancer Research Fund/American Institute for Cancer Research, 2007). WHO has further estimated that about 30 % of coronary heart disease and almost 20 % of all cases of stroke in developed countries is due to fruit and vegetables consumption levels below the recommended levels (Hammerschlag et al., 2008). Studies have moreover shown that consumption of plant based diets are associated with decreased prevalence of obesity, cardiovascular disease, cancer and overall mortality (Berkow and Barnard, 2006, Fraser, 2009, Li, 2011, Wyness et al., 2011). An adjustment of the balance between meat and plant based dietary components thereby seem to have a protective role against non-communicable diseases and have beneficial effects on public health in regions with affluent diets (Ferguson, 2010, Friel et al., 2009, WWF, 2011).

Diets with limited amounts of animal products are in addition favourable from a land use and food security perspective, as production of food from animal origin are far more land and energy intensive compared to food of vegetable origin (Gerbens-Leenes and Nonhebel, 2005, Hambraeus, in print). Livestock production currently occupies about 70 % of the global agriculture land and approximately one third of global arable land (Steinfeld et al., 2006). Based on result from available life cycle assessment studies production of 1 kg of chicken, pork and beef require 8-10 m^2, 9-12 m^2, 25-50 m^2 respectively (de Vries and de Boer, 2010), which can be compared with the approximately 1-2 m^2 for 1 kg of cereals (Gerbens-Leenes and Nonhebel, 2002). Modern animal production is further an inefficient way of producing food in terms of energy balance. To produce 1 kilogram of meat protein requires on average 6 kg of plant protein, resulting in a loss of around 80 % of the produced amount of protein and energy (Aiking, 2010).

5.3.2 Dietary recommendations for meat intake

From a nutritional point of view there are no general recommendations of how much meat is considered to be optimal for health. Existing recommendations on public health basis are instead usually based on a level that ensure sufficient intake of micronutrients, such as iron and zinc, without exceeding the upper limits of other intakes (such as energy, protein, total amount of fat, saturated fat, trans-fatty acids, cholesterol, salt). Data on meat consumption can either be given as raw weight or as weight after cooking. One kilogram of raw meat is roughly equivalent to 700 g cooked meat. The conversion factor will however depend on various factors such as the cut of meat, the proportions of lean and fat, as well as method and degree of cooking (World Cancer Research Fund/American Institute for Cancer Research, 2007).

Average meat consumption in the high income countries with affluent diets is around 94 kg per capita and year, corresponding to 260 grams per day (raw weight) (data for 2002) (FAOSTAT 2004 through Earth trends 2007). The actual intake of meat products, after adjustment of household food spoilage and waste, is lower. In Sweden for example the actual per capita meat intake (raw weight) has been estimated to 180 g day, 22 % lower than the estimate for available amount of meat (raw weight) per person in Sweden in the same year (230 g per day) (Lagerberg-Fogelberg, 2008, Swedish Ministry of Agriculture, 2010). If adjusting for household food spoilage and waste (assumed to be 11 %) (FAO, 2011b) and weight reduction by cooking (- 30 %), mean actual intake of cooked meat in high income countries would be around 160 g per day and up to 200 g per day in the countries with highest meat consumption (120 kilograms per capita and year).

To meet nutritional recommendations it has been stressed that reductions in meat consumption are needed in regions with affluent diet (Lagerberg-Fogelberg, 2008, Srinivasan et al., 2006). According to nutritional guidelines from different countries and organizations (Table 19) an intake between 50-100 g of cooked meat, equivalent to approximately 65-130 g in raw weight, alternatively replaced by plant based protein sources, is suggested to provide a balanced nutrient intake. Based on these recommendations current meat intakes in industrialized regions should be reduced, to meet health recommendations.

Table 19 Dietary meat recommendations

Dietary meat recommendations (cooked amounts)	Source
100 g per day*	National Food Administration of Sweden
98 g** per day	U.S. Department of Agriculture, U.S. Department of Health and Human Services
70-85 g*per day	Swiss Society of Nutrition
50-75 g per day	University of Melbourne, Australia
60-100 g* lean meat per day + occasional intake of charcuterie and fatty meat	La Sociedad Española de Nutrición Comunitaria, Spain
Less than 300 g red meat*** *per week* (43 g per day), avoid processed meat (public health goal)	World Cancer Research Fund/ American Institute for Cancer
Less than 300 g red meat*** *per week* (43 g per day), avoid processed meat	Health council of Netherlands, WHO Regional Office for Europe

*Weight reduction by cooking was assumed to be 30% of raw weight **No information was given on if data refers to raw weight or cooked weight. It is assumed that data refer to cooked amounts as ounce equivalents, which often refer to cooked amounts, was used as original unit. ***Red meat refers to beef, lamb and pork. Sources: (La Sociedad Española de Nutrición Comunitaria (SENC) and (semFYC), 2007, Larsen et al., 2011, Swedish National Food Administration, 2003, U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2010, Walter et al., 2007, World Cancer Research Fund / American Institute for Cancer Research, 2009, World Cancer Research Fund/American Institute for Cancer Research, 2007, European Commission, 2009).

Meat is however also a good source of many minerals (zinc, iron and selenium) and vitamins (vitamin D, B_3, B_6 and B_{12}) and contains all essential amino acids and significant amounts of omega-3 polyunsaturated fatty acids (Wyness, 2011). A reduced intake of meat without complementing with a balanced intake of other foods could thus lead to increased risk for nutrient deficiency (Millward and Garnett, 2010). This is particularly important for people with an inadequate energy intake (elders, sick, poor) or groups with increased nutritional requirements (fertile or pregnant women). The correlation between meat intake and increased risk for chronic disease have lately been questioned, with the arguments that observed negative health impacts are related to higher fat intake and cooking methods related to meat intake and not to the meat per se (Ferguson, 2010, Luciano, 2009, McAfee et al., 2010). A moderate intake of predominantly lean meat in balance with other dietary components thereby seems to be a good source of micronutrients also in a healthy diet (Millward and Garnett, 2010).

Reduced intake of meat and dairy foods has further been argued to be necessary to limit environmental damage (Garnett, 2011, Millward and Garnett, 2010) and could additionally result in reduced land use pressure. Ninety grams of meat per day with at most 50 gram coming from ruminant has been proposed as a working global target for stabilizing greenhouse gas emissions from the agriculture sector by 2050, relative its contribution in 2005 (McMichael et al., 2007). The amounts refer to available meat per person expressed in raw weight (McMichael, 2011), which means that the suggested amounts of cooked meat would be approximately 60 grams per day with at most 35 grams coming from ruminants (food losses and waste has not been taken into account). A reduction to 25 kilograms of meat per capita and year, corresponding to 68 grams raw or approximately 50 grams cooked meat, was in another study suggested to be required until 2050 to avoid a rise in livestock related greenhouse gas emissions compared to year 2000 (Garnett, 2008).

5.3.3 The effect of dietary change on land use

In a few studies the effect of dietary change on land use has been investigated by using different model-based scenarios (Table 20). Additional to these studies a projection has been done to investigate land and resource use in Australia under scenarios where a nutritionally adequate food supply is secured (Larsen et al., 2011). A few studies have further modelled the effect of dietary change on greenhouse gas emissions and other environmental impacts (European Commisson, 2009, Popp et al., 2010).

Table 20. Summary of studies analysing the effects of dietary change on land use change

Reference	Description	Scenario	Land use change (Mha, (%))***		
			Arable/crop-land	Pasture areas	Total agriculture area
(Stehfest et al., 2009)	Global perspective. Results are presented as the difference between scenarios of dietary change and a reference scenario, in 2050.	Substitution of all ruminant meat with plant protein	-91 (-6.0 %)	- 696 (-80 %)	-2787 (-57 %)
		Substitution of all meat by products with plant origin	-151 (-9.9 %)	-3370 (-100 %)	-3521 (-72 %)
		Diet based on dietary recommendations*	-135 (-8.8 %)	-1360 (-41 %)	-1495 (-31 %)
(Wirsenius et al., 2010)	Global perspective. Results are presented as the difference between scenarios of dietary change and a reference scenario, in 2030.	Increased livestock productivity (ILP)	-20 (-1.3 %)	-490 (-15 %)	-510 (-10 %)
		ILP + substitution of 20% of all ruminant meat with pork and poultry (RMS)	-59 (-3.9 %)	-935 (-28 %)	-994 (-20 %)
		RMS + substitution of up to 25 % of all meat with products of plant origin + reduce degree of food waste with 15-20% **	-105 (-6.9 %)	-1062 (-32 %)	-1167 (-24 %)
(Audsley et al., 2010a)	Results are presented as the difference between current consumption patterns *in the UK* and for scenarios of dietary change.	50% reduction in livestock consumption substituted by plant based products.	-0.6	-5-10	-5.6-10
(Audsley et al., 2010b)	Results are presented as the difference between current consumption patterns *in the UK* and for scenarios of dietary change.	50% reduction in consumption of products of animal origin substituted by plant products.	-0.56 (out of -0.26 in UK)	-8.3 (out of - 7.1 in UK)	-8.9 (out of - 3.0 tillable land)

		75 % reduction in consumption of beef and lamb substituted by poultry and pork.	+0.51 (out of + 0.04 in UK)	-8.8 (out of - 7.3 in UK)	-8.3 (out of - 1.7 tillable land)
		50 % reduction in consumption of white meat substituted by plant products.	-0.90 (out of - 0.19 in UK)	+/- 0	-0.9 (out of - 0.9 tillable land)
(Arnoult et al., 2010)	Results are presented as the difference between a healthy diet scenario *<u>in England and Wales</u>* and current intakes.	Increased consumption of fruit, vegetables, cereals and flour. Reduced intake of cheese, meat and products rich in sugar.	No significant change	Significant decrease	Decrease
(Westhoek et al., 2011)	Global land use perspective. Results are presented as the difference between scenarios of dietary change *<u>in the EU</u>* and a reference scenario, in 2030.	EU diets in 2020 in accordance with health recommendations****.	-40 (-2.6%) (out of +2 in EU)	-56 (-1.6%) (out of -3.3 in EU)	-96 (-2.0%) (out of -1.3 in EU)
		40 % reduction in consumption of red meat, in 2020, substituted by white meat.	-6 (-0.4%) (out of +3.4 in EU)	-33 (-1.0%) (out of -5.2 in EU)	-39 (-0.8%) (out of-1.8 in EU)
		Reduced consumption of animal products, by 10%.	-10 (-0.7%) (out of +2.6 in EU)	-23 (-0.7%) (out of -2.2 in EU)	-33 (-0.7%) (out of +0.4 in EU)
		Reduced consumption of animal products, by 20%.	-20 (-1.3%) (out of +3.1 in EU)	-32 (-1.0%) (out of -3.0 in EU)	-52 (-1.1%) (out of +0.1 in EU)
		Reduced consumption of animal products, by 50%.	-41 (-2.7%) (out of +5.7 in EU)	-65 (-1.9%) (out of-4.2 in EU)	-106 (-2.0%) (out of +1.5 in EU)
		*****			

*Daily intake of 10 g ruminant meat, 10 g pork and 46.6 g poultry and eggs. Increased intake of pulses and beans.
** In regions with high per capita meat consumption and high degree of food waste
***Relative change is calculated as the ratio of the land use change divided by the total agricultural area in 2008. Global crop-land=1527 Mha, global pasture land= 3357Mha, global agriculture land=4884 Mha. Population in UK: 62 million in 2009 (Croezen et al., 2010, Office of National Statistics, 2010). Population in EU27:500 million in 2009 (European Communities, 2009).
****Increased organic production, increased animal friendly production, reduced waste and increased efficiency were additional scenarios evaluated in this report.
*****Maximum consumption of red meat of 300 g per week, a minimum consumption of fish of 200 g per week, a daily consumption of milk of 400 g, a maximum consumption of fat of 30% of total caloric intake, a maximum consumption of saturated fat of 10% of caloric intake.

The results presented in Table 20 indicate that dietary change has a theoretical large potential of reducing global pressure on land use. Wirsenius (2010) showed that increased livestock productivity combined with a 20 % reduction of ruminant meat consumption replaced with poultry and pork, on global scale, could result in a decline in land use corresponding to almost one fifth of global agriculture areas. According to Stehfest (2009) even larger areas, in the magnitude of half of the world's agricultural land, could be released if all ruminant meat was substituted by plant protein.

Substitution of livestock products by food of plant origin appears to be the most efficient way of decreasing demand for land and reduce greenhouse gas emissions, in regard of changed consumption patterns. A transition towards less livestock-based diets, including a reduced intake of ruminants, would above all release grassland from former pasture areas. Some of the released grassland may have arable potential and could be used to grow crops for food production or bioenergy whereas others would be more suitable to be kept as permanent grassland. As discussed earlier (5.1.2) grazing on natural grassland have positive effects on biodiversity and contribute to carbon sequestration, why loss of pasture areas to some extent could lead to negative environmental consequences. When discussing decreased consumption of ruminant meat it is thus important to promote meat coming from sustainable production methods which contribute to open landscapes and increased biodiversity.

In most cases a shift towards less animal products also seems to result in a reduction of arable land due to decreased demand for feed crops. In the case studies from the UK (Audsley et al. 2010a, Audsley et al., 2010b) scenarios of dietary change, including reduced intake of all livestock products, ruminant meat and white meat, resulted in reductions of both pasture and arable land needs. Reductions in both arable land and grassland were also noted in the study which modelled reduced intake of animal products at EU level (Westhoek et al., 2011). The results suggest that the release of arable land currently used to grow animal feed in most cases will exceed the additional land required for increased crop production for direct human consumption. The net gain in arable land is however not obvious when consumption of plant protein substitute milk and other less land demanding animal products or when livestock products are substituted by highly refined meat analogues such as tofu and quorn (Stehfest, 2009;Audsley, 2010a).

The fact that ruminants require more land than monogastrics, and moreover are responsible for the majority of greenhouse gas emissions from the livestock sector, indicate that a change from ruminant meat towards pork and poultry would bring substantial environmental benefits. A swift towards increased consumption of pork and poultry may however increase the demand for feed concentrate produced overseas (Audsley et al., 2010b) resulting in a situation where the demand for land partly is exported to other countries where it might increase the risk for deforestation and other negative impacts connected to increased land use pressure. Such a situation has for example been noted in Brazil where increased cultivation of soy (and cattle ranching) has resulted in clearing of forest in the Amazonas (Fearnside, 2001, Nepstad et al., 2008, Nepstad et al., 2006). In the study by Westhoek et al. (2011) scenarios of reduced consumption of animal products and substitution of ruminant meat by pork and poultry on EU level however reduced demand for both arable and pasture land, with most pronounced effect outside of the EU. This indicate that reduced intake of ruminants could reduce land use pressure and have positive environmental effects also in areas outside of the EU. In the EU reduced consumption of animal products was projected to have a small effect on total demand of agriculture area, instead a reduced intensity on existing grassland and increased production of biofuel were expected local consequences (Westhoek et al., 2011).

A healthy diet characterized by decreased intake of meat and increased consumption of fruit and vegetables according to nutrition recommendations (in some of the scenarios also criteria regarding sugar and fish intake were stated), could according to the reviewed projections (Stehfest et al., 2009, Arnoult et al., 2010, Westhoek et al., 2011) result in considerable savings of land, in the magnitude of almost one third of global agriculture areas. The effect however seems to be largely dependent on the amount of meat included in the diet and be less influenced by the intake of fruit, vegetables, fish and sugar. A change towards a diet with a healthy intake regarding all food groups is however desirable from a nutrition perspective due to the positive effects on public health.

Considering the aspects discussed above the alternative associated with lowest risk for potential negative effects and largest benefits in terms of land use and climate change seem to be an overall reduction of animal products balanced by an increased amount of plant-based substitutes, which also goes is in line with recommendations from a health perspective.

5.4 Minimizing food losses and waste

To minimize losses and waste throughout the food supply chain might be the most efficient way of reducing demand for land and improve global food security. When food is spoiled and wasted, resource input and environmental impact associated with agricultural production, postharvest handling and storage, processing, distribution and consumption have occurred in vain.

5.4.1 Where in the supply chain is food spoiled and wasted?

Losses and waste of food is a global problem occurring along the entire food supply chain from the agricultural production to the consumer level. Where in the supply chain food losses occur varies between different commodities but also between developed and developing regions (FAO, 2011b). In developing countries the losses mainly occur early in the supply chain. Losses during agricultural production, postharvest handling and storage, mainly due to spillage or loss of quality and pests, are estimated to be in the magnitude of 12-32% of crop production in south- and south east Asia and sub-Saharan Africa (FAO, 2011b) but can be up to 80 % in extreme cases (Parfitt et al., 2010). In industrial countries a larger proportion of food is wasted in the later stages of the food supply chain (FAO, 2011b). Household food waste, believed to correspond to as much as 25 % of all food purchased (in UK, USA) (Kantor et al., 1997, WRAP, 2008) contributes significantly to food spoilage in the developed world (Parfitt et al., 2010, FAO, 2011b). Cereals, fruit, vegetables, bakery and dairy products, meat and fish are foods wasted in large quantities (Parfitt et al., 2010, FAO 2011b). In UK for example 45 % (by weight) of all purchased salad, 31 % of all bakery items and 26 % of all fruit is thrown away (WRAP, 2008). Although agricultural production and postharvest handling of food in general is more efficient in industrial countries compared to in low income countries, losses at earlier stages in the food supply chain can be substantial for certain commodities also in the developed world (FAO, 2011b). The negative consequences (economic and environmental) from spoilage of food increase the later in the food supply chain they occur.

5.4.2 How much food is spoiled and wasted?

Although food losses and waste has been a debated topic for several decades few attempts has been done to quantify the global magnitude of the problem. At what proportions food is lost in a global perspective is thus still uncertain and more research in this area is required. It has previously been estimated that "as much as half of all food produced may be lost or wasted before and after it reaches the consumer" (Lundqvist et al. 2008). Other estimates indicate that the global losses of food range between 10 and 50 per cent of the total production (Parfitt, 2010). Due to uncertainties in data and gaps in information it is impossible to make precise quantifications and so far there is no consensus of the proportions of global food that is lost. A recent study estimated that one third of the edible parts of food for human consumption, corresponding to 1.3 billion tonnes per year, is lost or wasted globally (FAO, 2011b). Expressed per capita the total amount of food loss was estimated to be 280-300 kilograms per year in Europe and North-America and 120-170 kilograms per year in sub-Saharan Africa and southeast Asia. The study was limited to include losses and waste from food for human consumption and did thus not include losses from crops dedicated to animal feed and other non-food uses. Figure 16 shows a schematic overview of the global amount of food produced (in the late 1990´s) and estimated total losses and wastage along the food chain, including the conversion from plant-based to animal based food.

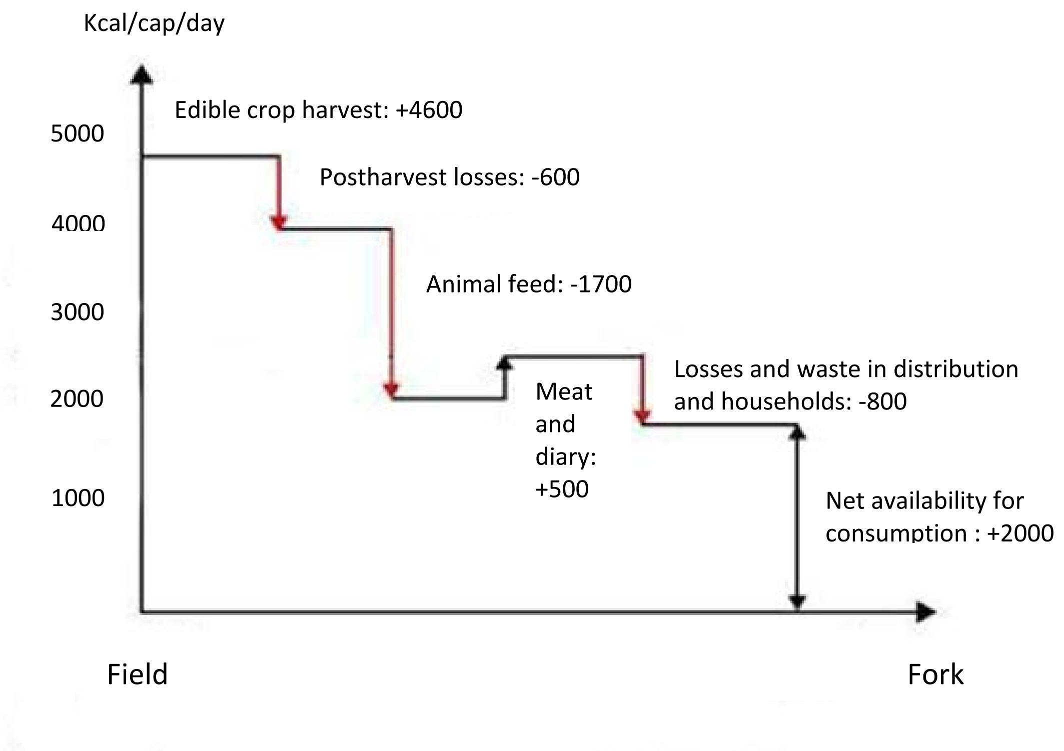


Figure 16. Global amounts of food produced and estimated losses and wastage in the food chain. Source: (Smil, 2000), adapted by (Lundqvist et al., 2008).

5.4.3 Potential for minimizing losses and waste

There are several trends in the modern society which are believed to influence the amount of food that is spoiled and wasted in the supply chain. Increased urbanization, globalisation of trade and consumer choice are all current trends believed to complicate the possibility of efficiency and increase the risk for losses along the supply chain (Parfitt et al., 2010). The nutrition transition, implying a shift from starchy staples towards more perishable food with shorter durability, has been identified as another driver for increased spoilage of food (Lundqvist et al., 2008). Growing income, resulting in an overall increase in food consumption, combined with a development towards larger availability and lower prices (Godfray et al., 2010b) has been pointed out as additional contributing factors for increased food waste (European Commission, 2010).

Different solutions for reducing food losses and waste are proposed depending on what stage in the food supply chain that is targeted and whether interventions are purposed for low or high income countries. In developing countries improved storage facilities and investment in agriculture infrastructure and technological skills are suggested to be key solutions for reducing food waste (Parfitt et al., 2010). In industrialized countries instead interventions aiming at; I) enhancing durability of food products, II) raising awareness of potential benefits associated with reduced losses throughout the food supply chain, III) changing customer behaviour and attitudes regarding food, and IV) improve waste management, are proposed to minimize food wastage (WRAP, 2010). Additional suggestions of how food losses can be prevented in different sectors throughout the food chain are summarized in the preparatory study on food waste across EU 27, carried out by the European Commission (2010). Development of biogas systems including anaerobic digestion of municipal food waste can further reduce the negative effects of food waste, but does not fully compensate for the total negative environmental effects.

Initiatives such as the Joint Declaration against food waste (Segrè et al., 2010) advocate a 50 % global reduction of food waste throughout the food chain by 2025. Such a reduction is thought to provide large savings in resource input and reduced environmental impact. Each tonne of avoided food waste has been estimated to save between 1.9 and 4.2 tonnes of CO_2-equivalents (European Commission, 2010, WRAP, 2008). The overall climate impact associated with food waste in Europe has been estimated to be at least 170 million tonnes of CO_2-equivalents, corresponding to about 3 % of total EU27 emissions in 2008 (European Commission, 2010). The results are in the same order of magnitude as in a study from United Kingdom (WRAP, 2011) showing that avoidable food waste accounts for approximately 3 % of the UK´s domestic greenhouse gas emissions. It has further been suggested that food waste accounts for more than one quarter of the fresh water consumption at global scale (Hall et al., 2009) and close to 6 % in the UK (WRAP, 2011).

The potential effect of reducing land use demand by minimizing food losses and waste has still not been explicitly investigated. The combined effect of a 25 % decrease in meat consumption and a 15-20 % reduction in food wastage at retail and household level in high-income countries has been suggested to decrease the demand for agriculture land with around 1200 million hectares compared to a reference case, until 2030 (Wirsenius et al., 2010). In another study a global 15 % reduction in losses of agricultural products decreased global demand for agriculture land by almost 5%, corresponding to approximately 250 million hectares, until 2030 (Westhoek et al., 2011). Assuming that one third of all cultivated crops is spoiled or wasted (FAO, 2011b), there is a theoretical potential of saving up to 1500 million hectares of agriculture land , by reducing losses and waste in the supply chain. In reality spoilage equivalent to a small proportion of produced agricultural crops is unavoidable why this quantification probably is overestimated. The calculation further assumes that a 30% reduction in losses of agriculture products would result in an equally large reduction in land needs which is a great simplification of a complex system with many influencing parameters.

5.5 Summary: Opportunities for minimizing land use conflicts

Predictions estimating further expansion of global arable land and increasing agricultural constrains demonstrate a need to develop strategies to meet potential risks of increased land use pressure. In chapter 5 the potential of increased land in cultivation, increased productivity, dietary change and minimizing food losses and waste have been discussed as possible opportunities of minimizing land use conflicts and open up for biomass utilisation options while securing the food supply.

Previous studies indicate that remaining land areas suitable for crop production to a large extent is covered by forest or pastures, particularly in developing regions, which leaves little room for further expansion of arable land. To expand crop areas options such as cultivation on abandoned arable land, pasture land or marginal land, thus has to be considered. The potential of expanding cultivated land on abandoned agriculture land, pasture and marginal land is still under investigation. The global extent of marginal and abandoned cropland with rainfed agricultural production capacity has been estimated to be in the range of 300-700 million hectares. Cultivation of abandoned and marginal farmland could to some extent hence be an option for increasing land in cultivation. Decreased biodiversity and release of soil carbon are potential environmental consequences that have to be considered when bringing marginal and abandoned arable land into cultivation. Marginal land however often refers to land with low biological diversity and which store little carbon. Systems based on perennial crops could further improve biodiversity and have beneficial effects on ecosystems with poor ecological conditions. Cultivation on marginal land has further been suggested to be a sustainable alternative for expansion of arable land, as land with low productivity often are of low competition for other usages such as food and feed crop production. Previous estimates indicate that there is a large potential, in the magnitude of 1400 million hectares, of expanding land for biomass production at expense of land currently used for livestock production. The trend towards a more intensive animal production has resulted in a development towards less extensive pasture areas in many regions, releasing land for other purposes. Grazing of land however contributes with several positive effects both in an ecological and social context, not at least as they can contribute to biodiversity by keeping landscapes open and act as sinks for carbon. Expansion of arable land on former pasture land could thus release large areas for cultivation but the opportunity has to be analysed from a broad environmental system perspective.

According to FAO´s projections food production must increase with 70 % until 2050 to meet the global demand. The majority of future increase in crop production is projected to come from an intensified agriculture production. Existing yield gaps between agro-ecologically attainable and current crop yields in various areas of the world indicate that there is a considerable potential to further increase yields with available technology. By increasing the productivity in crop and livestock production global biomass and food production yields could increase significantly and thereby prevent the need for expanding agriculture areas. Options of how to enable further increases in crop yields vary between different regions. In developing regions increased intensification in a traditional way could enable further substantial growth in crop and livestock production. Increased knowledge and development of novel technologies also provide new opportunities including advances in gene technology and the introduction of genetically modified crops. Intensification of the agriculture sector has historically had a high environmental price and has further been questioned from an animal welfare perspective. To increase productivity without risking negative environmental consequences there is a need for a sustainable intensification. Many options of both conventional and alternative farming methods exist that can make agriculture practice more sustainable. Organic agriculture is one example of a less intensive agriculture system. Limited usage of chemical compounds and farming methods that protect biodiversity and animal welfare are positive effects of organic production. Lower yields, insufficient quantities of organically acceptable fertilizers and the claim that organic agriculture cannot feed the world are commonly used arguments against organic production.

Excessive consumption and production of livestock is associated with several negative aspects including the effect on climate impact, public health, land use and food security. To meet nutritional recommendations it has been stressed that a substantial reduction in meat consumption is needed in regions with affluent diets. According to nutritional guidelines 50-100 g of cooked meat (approximately 65-130 g in raw weight), alternatively replaced by plant based protein sources, is suggested to provide a balanced intake of nutrients. Seventy to ninety grams of meat per day (raw weight) has further been proposed as a working global target for reducing climate impact from the agriculture sector. The current average meat consumption, of about 260 g per day (raw weight), in high income countries indicates that meat consumption should be reduced substantially to meet nutritional recommendations and climate goals. Previous studies further indicate that decreased consumption of animal products could have a large potential of reducing land use pressure. The largest savings in land in the reviewed studies come from scenarios where ruminant meat was replaced with plant based products. A shift from ruminant meat towards pork and poultry would primarily result in a release of pasture areas whereas the demand for feed concentrate may increase in some areas. Increased consumption of pork and poultry at expense of reduced intake of ruminants could thus have negative environmental effects related to loss of biodiversity due to reduced grazing and increased risk for deforestation in countries overseas. When discussing decreased consumption of ruminant meat it is thus important to have a broad environmental system perspective and to promote meat coming from sustainable production methods. The alternative of diet change associated with lowest risk for potential negative effects and largest benefits in terms of land use and climate change seem to be an overall reduction of animal products balanced by an increased amount of plant-based products, which also goes is in line with recommendations from a health perspective.

To minimize losses and waste throughout the food supply chain might be the most efficient way of reducing demand for land and improve global food security. It has been estimated that as much one third of all produced food in a global perspective is lost or wasted along the food supply chain. In developing countries the biggest losses occur early in the supply chain mainly due to spillage or loss of quality and pests. In industrial countries a large part of the losses instead comes from household food waste, believed to correspond to as much as 25 % of all food purchased. Different solutions for reducing food losses and waste are proposed depending on what stage in the food supply chain that is targeted. In developing countries improved storage facilities and investment in agriculture infrastructure and technological skills are suggested to be key solutions for reducing food waste. In industrialized countries instead interventions aiming at; I) enhancing durability of food products, II) raising awareness of potential benefits associated with reducing losses throughout the food supply chain, III) changing customer behaviour and attitudes regarding food, and IV) improve waste management, are proposed to minimize food wastage. The potential effect of reducing land use demand through minimizing food spoilage has not been explicitly investigated. Previous studies however indicate that reducing food losses and waste could be an effective strategy for reducing greenhouse gas emissions, water consumption and land use pressure.

Overall the identified strategies for minimizing land use pressure seem to be able to reduce current global agriculture areas considerably. Figure 17 illustrates drivers for increased land use pressure and opportunities for minimizing land use pressure.

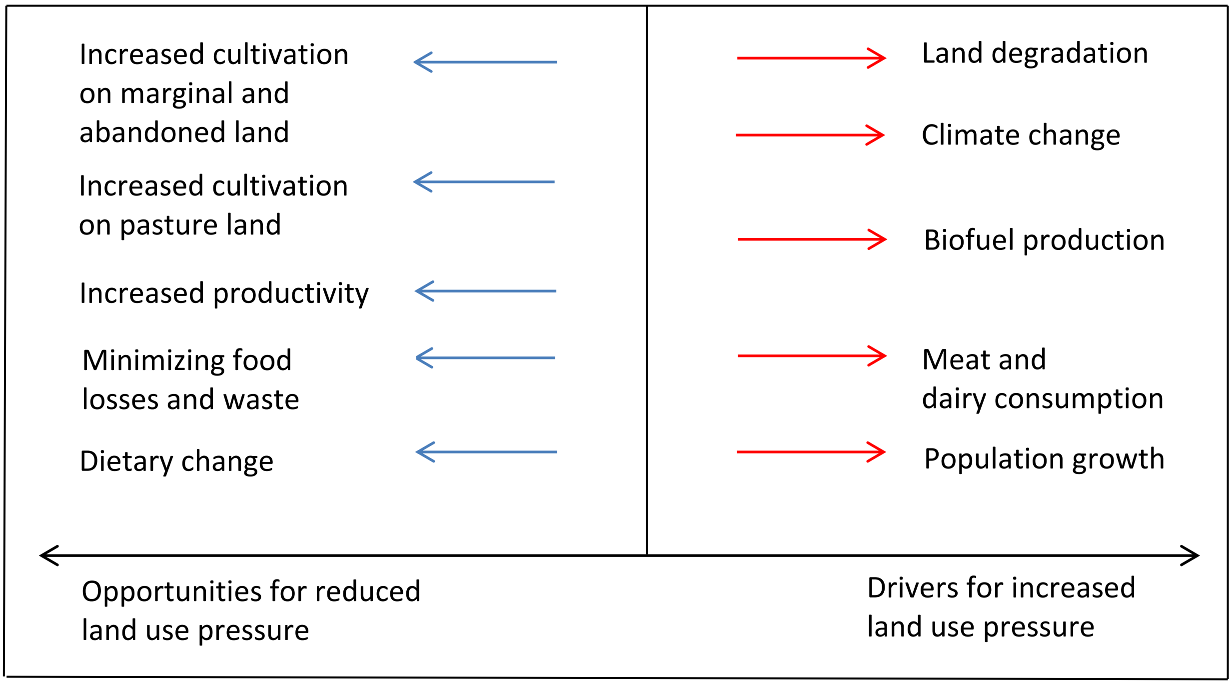


Figure 17. Drivers for increased land use pressure and opportunities for reduced land use pressure

6 DISCUSSION

In the previous chapters we have described key issues related to land use for production of food, feed and biofuel and analysed available opportunities for minimizing land use conflicts. Land use management is closely linked to challenges affecting both food security and the environment why it is of great importance to address and find solutions to questions concerning global land distribution. In the following sections (6.1-6.4) we will describe available options to meet future demand of food and energy and discuss whether it is possible to secure global demand for food in a sustainable way, at the same time as parts of global agriculture areas are used for production of biofuels.

6.1 Risks and opportunities

This report shows that production of biomass for food and feed occupies large land areas and that unsustainable land use management in some areas is a driver behind deforestation, land degradation and other environmental impacts, resulting in increasing ecological stress. Growing demand for agricultural products, including biofuels, could thus result in negative environmental consequences and threaten land currently suitable for agriculture. The up going trends with a global increase in demand for livestock products, bioenergy and other challenges, such as land degradation, climate change and population growth, project a further increase in demand of biomass in a future where areas of available and suitable agriculture land will be limited. These trends demonstrate a great need to develop strategies to meet potential risks of increasing land use conflicts.

Although increased land use pressure is a global trend, available research indicate that there are options for more sustainable land use practice and reduced land needs. In this report redistribution of current agriculture land, sustainable intensification of agriculture, dietary change and minimizing of food losses and waste are suggested as available opportunities for minimizing land use conflicts. To increase productivity and land in cultivation enables a further increase in biomass production but also entails a risk for environmental negative consequences, if not carried out with a sustainable approach. It is thus of great importance that potential effects are analysed from a broad system perspective. Dietary change and optimization of methods to avoid food spoilage along the supply chain are other available options for saving land. These options in contrast seem to involve mainly positive effects which could provide benefits from both an economic, environmental and health perspective.

Although it is uncertain what the future will bring, a worst and best case scenario could be imagined as a possible window of opportunity. If current trends will continue we can expect a future where increased production of biomass could lead to consequences such as continued deforestation, increased land degradation, elevated temperatures and loss of productivity on current farm land. However, by taking action there still seems to be a potential to curb this prospect and implement changes resulting in a more sustainable use of land. In this way a more sustainable future scenario could become reality. In such a scenario prevention of further expansion of agriculture land could reduce the rate of deforestation in areas of high ecological value. Farming practise which protects biodiversity and ecosystem services provided by nature could contribute to agriculture with high productivity in both a short and long term perspective. Development of new technologies and more efficient production and handling of food could further minimize resource use, land requirements and environmental impact from food production.

6.2 Need for more efficient systems

The fact that almost one billion people lack adequate food for the day, although enough food is produced to feed our world, indicate that current biomass resources are mismanaged. There is thus a need for a more efficient and fair use of produced biomass. To achieve a more sustainable production of food and other bio-products, improved productivity therefore has to be combined with other measures such as redistribution of agriculture land and better handling and distribution of produced biomass. This would be possible if existing agriculture land was used in a way which optimizes output of energy and nutrition in an efficient and sustainable way. Current use of agriculture land and production of biomass is in our opinion not efficient in terms of an optimized production of food and non-food products. This is obvious from the two facts that around one third of all food produced is spoiled or wasted and secondly animal production covers 70% of global agriculture areas while providing less than 15% of global dietary energy.

This report has shown that substantial land areas theoretically could be saved by preventing losses and waste of agricultural products and by changing dietary habits. The common benefits from a land use, environmental, health and economic perspective should be strong incentives for promoting dietary change and reduced food losses. To implement changes in society towards a more efficient use of agricultural crops, a better synergy between agriculture, health and environmental policy is required. There is also an urgent need of better understanding of how food spoilage and waste can be minimized and how to change dietary preferences in regions with affluent diet.

6.3 The local perspective

When answering the question whether it is possible to secure global demand for food at the same time as parts of agriculture areas are used for production of biofuels, we believe that it is important to distinguish between regions with different conditions. In some regions increased production of biomass could lead to expansion of agriculture land on areas of high ecological value and unsustainable farming practice with adverse effects on the environment. However, in other regions increased productivity and unchanged demand for agriculture products is releasing former agriculture land. This land could either be used for increased production of biomass or be seen as a buffer of farm land, which could be used for increased food production in the future.

6.4 The way forward

When discussing the complex matter of sustainable use of agriculture land we believe that an interdisciplinary perspective is needed, where both environmental and ethical dimensions are considered. This goes for production of bioenergy as well as for production of food, feed and other bio-based products. To produce enough food and prevent food insecurity should always have the highest priority in terms of agriculture production. A change from fossil fuels towards renewable energy in the transport sector, in combination with a significant improvement in energy efficiency, is however essential for a sustainable development. Efforts to halt climate change are also directly decisive for future food security, particularly in poor regions in the southern hemisphere. To ensure long term access of energy is moreover a prerequisite for production and availability of food. In this way it could be argued that production of bioenergy from parts of agricultural land will improve the prospects for food security, if produced in a sustainable way.

We suggest that there are viable options which could result in substantial reductions in demand for agricultural land without increasing the risk for food insecurity and negative consequences for the environment. This could open up for a situation where parts of global agriculture areas could be used for other purposes, such as production of biofuels. A limited production of first generation biofuels to mitigate climate impact from the transport sector thereby seems to be a viable option in the short term until second generation biofuels and other technologies become available on the market. As the world population is increasing, cultivation for biofuel production might have to be reduced to make room for increased food production on existing agriculture land. Figure 18 illustrates possible scenarios of how global agriculture land could be distributed between food and first generation biofuel production.

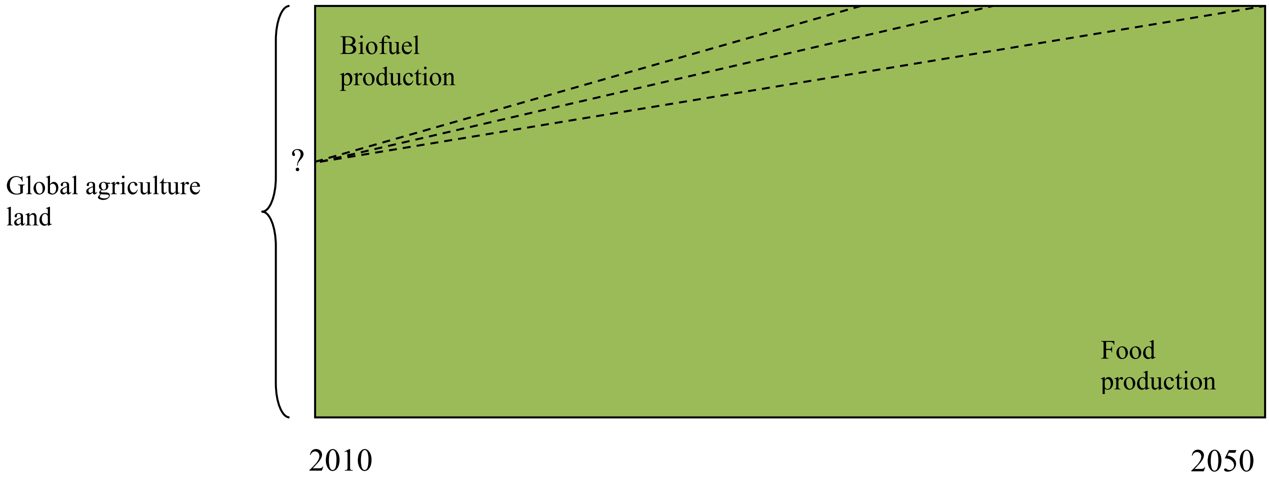


Figure 18. Schematic picture of possible scenarios of distribution of global agriculture land between food and biofuel production based on agricultural crops

Based on current knowledge there is hence an urgent need for action in the near future to avoid land use conflicts which could have serious environmental consequences and threaten food security. We claim that there is available knowledge of options to reduce land requirement and make farming more sustainable, that could be implemented in the society today. However there is also a need for further research in areas which can complement and develop the current state of knowledge.

7 CONCLUSIONS

In this report challenges and opportunities for future production of food, feed and biofuels have been discussed from a land use perspective. The overall conclusions of the report are:

Available research indicate that options such as redistribution of agriculture land, development of new techniques and sustainable farming methods, dietary change and reduction of food losses and waste offer significant opportunities to reduce current and future land use pressure without increasing the risk for negative consequences on food security and the environment.

The report suggests that a limited production of first generation biofuels, to mitigate climate impact from the transport sector, is a viable option in the short/medium term, until second generation biofuels and other technologies become available on the market. The development towards a sustainable use of land, for production of food, feed and biofuels however has to be evaluated from a broad system perspective where both environmental and ethical dimensions are considered.

There is an urgent need for action in the near future to avoid increasing land use conflicts and environmental impact. For this further research is in needed to complement current state of knowledge. Below identified areas in need of further research are listed:

i. Scenario analysis which project the combined effect that agriculture constrains, such as land degradation, water shortage and climate change, will have on future biomass production.

ii. Scenario analysis of interdisciplinary character which investigate the overall impact that options, such as redistribution of agriculture land, increased productivity, dietary change and minimizing food losses, will have on land use and the environment.
iii. Research which from a broad system perspective study the effect that dietary change, in particular reduced meat and dairy consumption, will have on the environment, health and economy.
iv. Research developing concrete strategies for improved dietary habits which are sustainable from both an environmental and health perspective.
v. Research developing concrete strategies for minimizing food spoilage along the food supply chain.
vi. Research which from a broad system perspective, including both environmental and social dimensions, identify regions more and less suitable for non-food production of biomass.
vii. Research developing concrete recommendations and strategies for better synergy between agriculture, health and environmental policy.

However there is also available knowledge of ways to reduce land requirement and make farming more sustainable, that could and should be implemented in the society today. Thus, action from policy makers is needed already today for developing and introducing new and innovative policy instruments which include a much broader perspective than today.

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9 APPENDIX A. COUNTRY GROUPS ACCORDING TO CLASSIFICATIONS OF THE UNITED NATIONS STATISTICS DIVISION

Developed and developing regions

Developing regions

Africa
Americas excluding Northern America
Caribbean
Central America
South America
Asia excluding Japan
Oceania excluding Australia and New Zealand

Developed regions

North America
Europe
Japan
Australia and New Zealand

Least developed countries

Afghanistan
Angola
Bangladesh
Benin
Bhutan
Burkina Faso
Burundi
Cambodia
Central African Republic
Chad
Comoros
Democratic Republic of the Congo
Djibouti
Equatorial Guinea
Eritrea
Ethiopia
Gambia
Guinea
Guinea Bissau
Haiti
Kiribati
Lao People´s Democratic Republic
Lesotho
Liberia
Madagascar
Malawi

Mali
Mauritania
Mozambique
Myanmar
Nepal
Niger
Rwanda
Samoa
Sao Tome and Principe
Senegal
Sierra Leone
Solomon Islands
Somalia
Sudan
Timor-Leste
Togo
Tuvalu
Uganda
United Republic of Tanzania
Vanuatu
Yemen
Zambia

Transition countries

Armenia
Azerbaijan
Belarus
Kazakhstan
Kyrgyzstan
Republic of Moldova
Russian Federation
Tajikistan
Turkmenistan
Ukraine
Uzbekistan
Albania
Bosnia and Herzegovina
Croatia
Montenegro
Serbia
The former Yugoslav Republic of Macedonia

Source: (United Nations, 2011)