BIOENERGY: RISKS TO FOOD-, ENERGY- AND ENVIRONMENTAL SECURITY

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Abstract: There are growing opportunities and demands for the use of biomass to provide additional renewables, energy for heat, power and fuel, pharmaceuticals and green chemical feedstocks. However, the worldwide potential of bioenergy is limited, because all land is multifunctional, and land is also needed for food, feed, timber and fiber production, and for nature conservation and climate protection. The recent expansion of the bioenergy industries together with a strong increase in many commodity prices has raised concerns over the land use choices between energy needs and food and feed. New systems of energy production must be developed based on cost of environmental damage due to production and use of fossil energy and certain chemicals and materials. This article presents risks to food and energy security, estimates of bioenergy potential and the challenges of the environmental and social impact associated with expansions in bioenergy production.

Key words: food security, energy security, bioenergy production, biomass potential, environmental impact

1. Introduction

The world's population continues to grow and, over the next 40 years, agricultural production will have to increase by some 60%. Higher food, feed and fiber demand will place an increasing pressure on land and water resources, whose availability and productivity in agriculture may themselves be under threat from climate change. The additional impact on food prices of higher demand for crops as energy feedstock is of real concern.

In the last 35 years global energy supplies have nearly doubled but the relative contribution from renewables has hardly changed at around 13%. Continued reliance on fossil fuels will make it very difficult to reduce emissions of greenhouse gases that contribute to global warming. Bioenergy currently provides roughly 10% of global supplies and accounts for roughly 80% of the energy derived from renewable sources. Bioenergy was the main source of power and heat prior to the industrial revolution. Since then, economic development has largely relied on fossil fuels. A major impetus for the development of bioenergy has been the search for alternatives to fossil fuels, particularly those used in transportation. The renewed interest in biofuel is driven by a range of considerations, including climate change and the potential economic contribution of the development of the biofuel industry in terms of income and employment.

The development of biofuels has been one of the most visible and controversial manifestations of the use of biomass for energy. Furthermore, an ongoing debate about the benefits of reliance on biofuels derived from food crops and concern about the efficacy of current biofuels policies may contribute to the doubts of future policy. While biofuel has the potential to be more environmentally friendly in terms of reduced greenhouse gas (GHG) emissions, it may have unintended negative environmental consequences, particularly relating to changes in land use. Characterizing and quantifying the relationship between biofuel production and the environment poses a considerable challenge. In combination with an improved assessment of the effects of indirect land use change and an expansion of sustainability criteria to biomass production in general could help in integrating energy, agricultural, environmental and international trade policies to develop renewable energy in a sustainable way. A broader, more integrated approach is needed to energy policy, embracing all renewable energies that reduce GHG emissions without serious side-effects.

2. Material and methods

The paper is based on publications addressing the effect of bioenergy expansions in terms of food- energy-, environmental and social security. Data published in various international journals and books were used in the analysis. The database of the Organisation for Economic Co-operation and Development, Food and Agriculture Organization of the United Nations, International Energy Agency, Intergovernmental Panel on Climate Change, European Commission has also been used in the examination. The literature on the impacts of bioenergy expansions is already substantial. Several reports have addressed the effects of bioenergy on food, energy and the environment. However, the effects of bioenergy, first of all biofuel, production on land use and GHG emissions have received much less attention. Furthermore, there is a lack of available publications related to the feed value of increasing biofuels by-products, which are supposed to be credited with the area of cropland required to produce the amount of feed they substitute. The use of individual studies is furthermore hampered by the fact that these studies might use totally different methodologies (and motivations) to assess the environmental and social effects of bioenergy expansion. In addition, results are potentially biased because studies might differ in their focus on potential or realized effects, their use of different baselines for comparisons and other background conditions. Most studies and surveys capture information only over a short period of time, longer-term market responses to the expansion of bioenergy are not reflected in the analysis.

3. Results

Land use for food and feed are typically determined by global diet and agricultural yield improvements. Helping farmers lose less of their crops will be a key factor in promoting food security. Due to high dependence of the global food sector on fossil fuels the volatility of energy markets can have a potentially significant impact on food prices leading to increasing food insecurity.

In the last 35 years global energy supplies have nearly doubled but the relative contribution from renewables has hardly changed at around 13%. It is estimated that renewable energy accounts for 13% of the total global primary energy supply, however, the contribution of renewable energy to primary energy supply varies substantially by country and region. The largest contributor to renewable energy with 10% points is biomass (bioenergy), whereas other renewable energy sources account for 3% point. Although the worldwide potential of bioenergy is limited because all land is multifunctional, it still has the highest technical potential for expansion as the largest single source of renewable energy today. The majority of biomass is used inefficiently for traditional domestic cooking, lighting and space heating in developing countries but the share of modern bioenergy use is growing rapidly. Biomass also provides an attractive feedstock for the chemical industry since the use of biogenic fibres will increase in the future.

Projected world primary energy demand by 2050 is expected to be in the range of 600 to 1000 EJ/year compared to current 500 EJ/year. The total annual aboveground net primary production on the Earth's terrestrial surface is estimated to be about 1260 EJ/year, which can be compared all harvested biomass used for food, fodder, fibre and forest products of 219 EJ/year. The global harvest of major crops and industrial roundwood corresponds to about 80 EJ/year. The technical potential for biomass is estimated to be as high as 1500 EJ/year by 2050. However, scenarios taking into account sustainability constraints indicate an annual potential of 200–500 EJ/year representing 40 to 100% of the current global energy use. The expert assessment suggests potential deployment levels of bioenergy by 2050 in the range of 100–300 EJ/year contributing between a quarter and a third of the future global energy mix.

Bioenergy has significant potential to mitigate GHGs if resources are sustainably developed and efficient technologies are applied. The impacts and performance of biomass production and use are region- and site-specific. The precise quantification of GHG savings for specific systems is often hampered by lack of reliable data. Furthermore, different methods of quantification lead to variation in estimates of GHG savings. Nonetheless practically all bioenergy systems deliver large GHG savings if they replace fossil-based energy and if the bioenergy production emissions – including those arising due to land use change – are kept low.

Biomass for energy is only one option for land use among others, and markets for bioenergy feedstocks and agricultural commodities are closely linked. The direct land-use change effects of bioenergy production can be controlled through certification systems, wherever biomass is grown. Indirect land-use changes, however, are more difficult to identify. Most current biofuel production systems have significant reductions in GHG emissions relative to the fossil fuels displaced, if no indirect land-use change effects are considered. The debate surrounding biomass in the food versus fuel competition has resulted in the fast development and implementation of sustainability criteria biomass and biofuels certification and standards as voluntary or mandatory systems reducing potential negative impacts associated with bioenergy production. Such criteria do not apply to conventional fossil fuels. A proliferation of standards increases the potential for inefficiencies in the market and abuses such as "shopping" for standards that meet particular criteria. Lack of international systems may cause market distortions instead of promoting the use of sustainable biofuels production. Production of "uncertified" biofuel feedstocks will continue and enter other markets in countries with lower standards or for non-biofuel applications that may not have the same standards.

The transport sector is responsible for about 20% of world primary energy demand. Transport biofuels are currently the fastest growing bioenergy sectors even they represent just 3% of total road transport fuel and only 5% of total bioenergy consumption today. Common transport policies include biofuel subsidies, tax exemptions, blending mandates and the introduction of flex-fuel vehicles. Liquid biofuels for transport are generating the most attention, although only a small fraction of biomass is used globally for biofuels production at present. Changes in land use, principally those associated with deforestation and expansion of agricultural production for food, contribute about 15% of global emissions of GHG. Currently, less than 3% of global agricultural land is used for cultivating biofuel crops and land use change associated with bioenergy represents only around 1% of the total emissions caused by land-use change globally most of which are produced by changes in land use for food and fodder production, or other reasons. The proportion of global cropland used for biofuels is currently some 2.5% (40 million gross hectares) with wide differences among countries and regions. The biofuel production processes give rise to by-products which are largely suitable as animal feed. By-products are supposed to be credited with the area of cropland required to produce the amount of feed they substitute. By adding by-products substituted for grains and oilseeds the land required for cultivation of feedstocks declines to 1.5% of the global crop area (net land requirement). Based on the land-use efficiencies land use for biofuel production would need to increase from 40 million hectares (21 million hectares net land requirement by adding by-products substituted for grains and oilseeds) to around 100 million hectares in 2050. This corresponds to an increase from 2.5% of total arable land today to around 6% in 2050.

4. Discussion

4.1. Risks to food security

One-quarter of all agricultural land is highly degraded, yet over the next 40 years, agricultural production must increase by 60%, sustainably and with fairer distribution, to provide global food security, a major contributor to social stability (*OECD/FAO, 2012*). For the past decade, yield increases on farms have been limited or static for most major crops despite the increasing genetic potential provided by improved varieties. The need to increase agricultural productivity and efficiency in developed as well as in developing countries is now well accepted. Producing more food sustainably requires crops that make better use of limited resources including land, water and fertiliser.

With respect to diet, consumption of meat and dairy products is an important driver for land use since meat and dairy use a lot more basic agricultural production than does the consumption of grain. Livestock products imply an inefficient conversion of calories of the crops used in livestock feeds. On average, 6 kg of grain is required to yield 1 kg of meat. Meat consumption is projected to rise nearly 73% by 2050; dairy consumption will grow 58% over current levels. The surge in livestock production that took place over the last 40 years resulted largely from an increase in the overall number of animals being raised. Meeting projected demand increases in production will need to come from improvements in the efficiency of livestock systems in converting natural resources into food and reducing waste. This will require capital investment and a supporting policy and regulatory environment. Meat consumption in China alone increased from 27 to 60 kg per person per year between 1990 and 2010. Each additional kg of meat consumption increase in China results in a need for roughly 4–5 million tons of animal feed (*FAO, 2011a*). Roughly one-third of the edible parts of food produced for human consumption, gets lost or wasted globally. Food losses in industrialized countries are as high as in developing countries, but in developing countries more than 40% of the food losses occur at post harvest and processing levels, while in industrialized countries, more than 40% of the food losses occur at retail and consumer levels (*Gustavsson et al., 2011*). We can save also water and energy by reducing losses in the food chain.

Land use change is not a new concept but is something that has been taking place since the beginning of civilization and continues to do so. In this context, agriculture has always been an important driver, so far mostly for food and feed production. A growing world population and a changing diet have led to continuously expanding areas of agricultural land, despite parallel increases in yields from existing cropland. On the other hand cultivated land is tightening due to population growth and accelerated urbanization and motorization[1], changes in lifestyles, falling water tables and diversion of irrigated water towards the cities (*The Earth Institute, 2005*). Future food security depends on the development of the political and logistical capacity to make food accessible everywhere, to every (*FAO, 2011b*). Around 0.9 billion people are undernourished. There will always be risks associated with food supply and thus a need to manage these risks. Domestic food supplies are not less risky than for example energy imports, but it is sensible to plan for systemic risks (such as nuclear fallout, port strikes, etc.). We experience food poverty due to a lack of entitlements, not lack of food availability (*Krugman, 2009*). Future food security depends on the development of the political and logistical capacity to make food accessible everywhere, to everyone.

Bioenergy may compete with the food sector, either directly, if food commodities are used as the energy source, or indirectly, if bioenergy crops are cultivated on soil that would otherwise be used for food production. Both effects may impact on food prices and food security if demand for the crops or for land is significantly large. This issue has typically been of concern for the biofuels sector, which uses mainly food crops. Increased biofuels production could also reduce water availability for food production, as more water is diverted to production of biofuel feedstocks (*FAO, 2011c; IEA Bioenergy, 2009*). Until now, the price increases that this has led to seem to be limited for most crops, and the agricultural sector has responded by increasing production. There are exceptions, though, especially with crops where biofuel demand accounts for a significant share of total demand (e.g. maize, oilseeds, sugarcane).

[1]An estimated 40,000 ha of land are needed for basic living space for every 1 million people added and 20,000 ha of land are needed for every 1 million vehicles added.

4.2. Risks to energy security

The use of fossil fuels by agriculture has made a significant contribution to feeding the world over the last few decades. The food sector accounts for around 30% of global energy consumption and produces over 20% of global greenhouse gas (GHG) emissions. Around one-third of the food we produce, and the energy that is embedded in it, is lost or wasted. The energy embedded in global annual food losses is around 38% of the total final energy consumed by the whole food chain *(Gustavsson et al., 2011).* Due to high dependence of the global food sector on fossil fuels the volatility of energy markets can have a potentially significant impact on food prices, and this would have serious implications for food security and sustainable development *(IPCC, 2011).* Rising energy prices may cause spillovers into food markets leading to increasing food insecurity. Furthermore, any increase in the use of fossil fuels to boost production will lead to greater GHG emissions, which the global community has pledged to reduce *(FAO, 2011c)*.

Global primery energy demand is projected to rise from around 12 300 million tons oil equivalent (Mtoe) in 2008 to 16 800 Mtoe in 2035 – an increase of over 35%. On a global basis, it is estimated that renewable energy accounted for 13% of the total 492 Exajoules (EJ)[2] of primary energy supply in 2008 (*IEA Bioenergy, 2009*). The largest contributor to renewable energy with 10% points was biomas. Hydropower represented 2% points, whereas other renewable energy sources accounted for 1% point *(Figure 1).* The contribution of renewable energy to primary energy supply varies substantially by country and region. While oil continues to be the dominant fuel in the primary energy mix, its share of the mix drops from 33% in 2008 to 27% in 2035. Natural gas increases from 21% of the global fuel mix in 2008 to 25% in 2035 becoming the second-largest fuel in the primary energy mix. The share of primary coal demand declines by 5% from 27% in 2008 to 22% in 2035. The share of nuclear power in global primary energy supply increases from 6% in 2008 to 7% in 2035 (*IEA, 2011*). Renewables increase from 13% of the mix to 19% over the same period leading to a decreasing share of fossil fuels in the global primary energy consumption from 87% in 2008 to 81% in 2035 (*Figure 1 and Figure 2*).

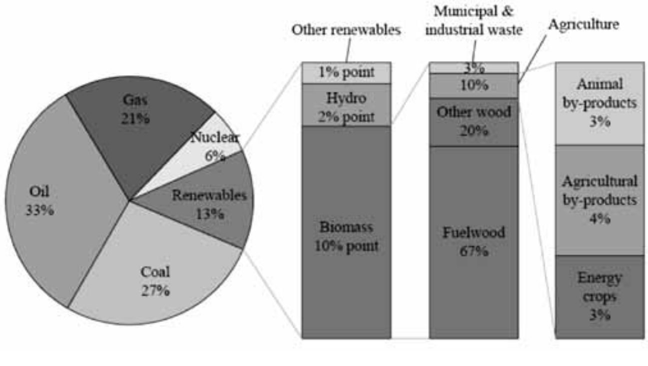

Figure 1: World primary energy demand by fuel in 2008.
Source: IEA Bioenergy, 2009

[2]1 Exajoule = 1018 joules = 23.88 million tons of oil equivalent (Mtoe).

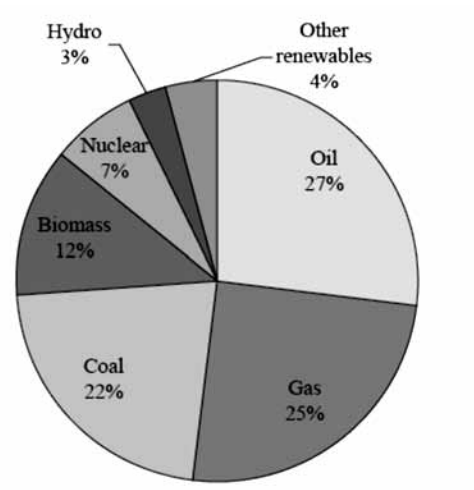

Figure 2: World primary energy demand by fuel in 2035.
Source: IEA Bioenergy, 2009

4.2.1. The increasing competition for biomass: bioenergy potential

Overall, the global share of biomass has remained stable over the past two decades, but in recent years a sharp decline in share can be observed in China due to a rapid growth of total energy consumption and a steady increase of all types of biomass (for electricity, heat and biofuels) in the EU. The worldwide potential of bioenergy is limited because all land is multifunctional and land is also needed for food, feed, timber and fibre production, as well as for nature conservation and climate protection. In addition, the use of biomass as an industrial feedstock (e.g. plastics) will become increasingly important. At present only a small fraction of biomass is used globally for biofuels production and power generation, but these shares are growing rapidly because of issues like energy security, rising fossil fuel prices and, last but not least, global warming concerns and greenhouse gas reduction policies. With demand for energy continuing to rise in absolute terms, the absolute use of biomass will increase even more.

Bioenergy is the largest single source of renewable energy today and has the highest technical potential for expansion amongst renewable energy technologies. In 2008, biomass provided about 10% (50.3 EJ/year) of the global primary energy supply. More than 80% of the biomass feedstocks are derived from wood (trees, branches, residues) and shrubs. The remaining bioenergy feedstocks came from the agricultural sector (energy crops, residues and by-products) and from various commercial and post-consumer waste and by-product streams (biomass product recycling and processing or the organic biogenic fraction of municipal solid waste *(Figure 3).*

The majority of biomass (roughly two-thirds) is used inefficiently for traditional domestic cooking, lighting and and space heating in developing countries. The share of the smaller, modern bioenergy use is growing rapidly. High-efficiency modern bioenergy uses more convenient solids, liquids and gases as secondary energy carriers to generate heat, electricity, combined heat and power, and transport fuels for various sectors. The estimated total primary biomass supply for modern bioenergy is 11.3 EJ/year or 22% of world biomass demand. Additionally, the industry sector consumes approximately 7.7 EJ of biomass annually or 15% of world biomass demand, primarily as a source for industrial process steam (*IEA, 2011*).

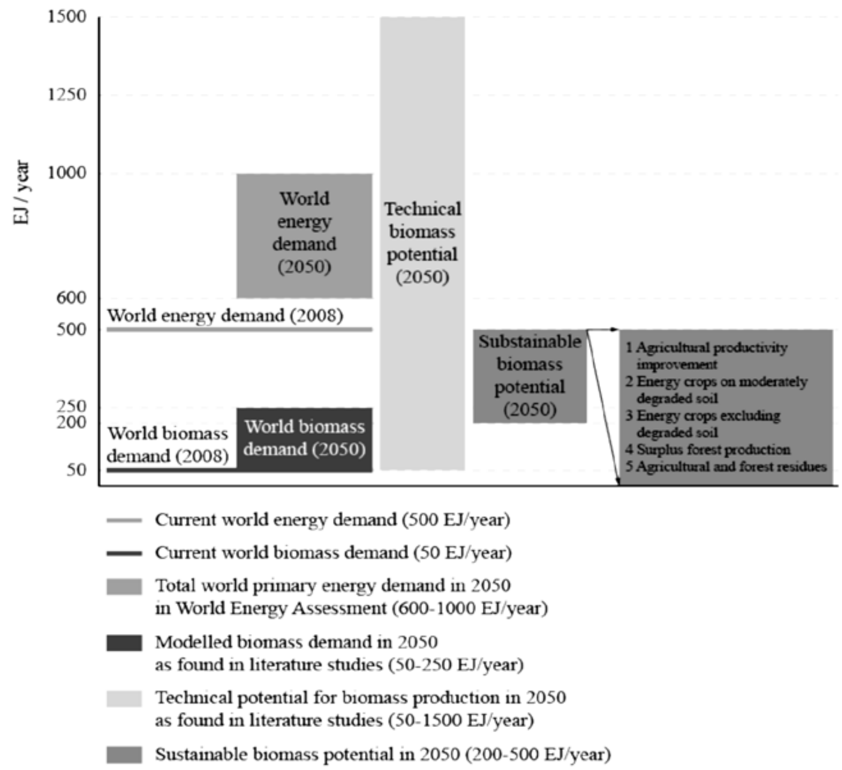

***Figure 3**:* Global bioenergy sources.
Source: IEA Bioenergy, 2009

The total annual aboveground net primary production (the net amount of carbon assimilated in a time period by vegetation) on the Earth's terrestrial surface is estimated to be about 35 Gt carbon, or 1 260 EJ/year assuming an average carbon content of 50% and 18 GJ/t average heating value (*Haberl et al., 2007*), which can be compared to the current world primary energy supply of about 500 EJ/year (*IEA Bioenergy, 2009*). All harvested biomass used for food, fodder, fibre and forest products, when expressed in equivalent heat content, equals 219 EJ/year (*Krausmann et al., 2008*). The global harvest of major crops (cereals, oil crops, sugar crops, roots, tubers and pulses) corresponds to about 60 EJ/year and the global industrial roundwood production corresponds to 15 to 20 EJ/year (*FAOSTAT, 2011*).

Based on this diverse range of feedstocks, the technical potential for biomass is estimated in the literature to be possibly as high as 1 500 EJ/year by 2050 (*Smeets et al, 2007*). However, most biomass supply scenarios that take into account sustainability constraints, indicate an annual potential of between 200 and 500 EJ/year (excluding aquatic biomass owing to its early state of development), representing 40 to 100% of the current global energy use (*IEA Bioenergy, 2009*). Forestry and agricultural residues and other organic wastes (including municipal solid waste) would provide between 50 and 150 EJ/year, while the remainder would come from energy crops, surplus forest growth, and increased agricultural productivity (*Figure 3*).

Projected world primary energy demand by 2050 is expected to be in the range of 600 to 1 000 EJ/year compared to about 500 EJ in 2008. The expert assessment suggests potential deployment levels of bioenergy by 2050 in the range of 100-300 EJ/year. However, there are large uncertainties in this potential, such as market and policy conditions, and there is strong dependence on the rate of improvements in the agricultural sector for food, fodder and fibre production and forest products. The entire current global biomass harvest would be required to achieve a 200 EJ/year deployment level of bioenergy by 2050. Scenarios looking at the penetration of different low carbon energy sources indicate that future demand for bioenergy could be up to 250 EJ/year *(Kampman et al., 2010).* It is reasonable to assume that biomass could sustainably contribute between a quarter and a third of the future global energy mix.

The transport sector is responsible for about 20% of world primary energy demand (94 EJ). Transport biofuels are currently the fastest growing bioenergy sector. However, today they represent just 3% (2.4 EJ) of total road transport fuel consumption and only 5% of total bioenergy (in energy value). At present only a small fraction of biomass (sugarcane, grain, and vegetable oil crop) is used globally for biofuels production, but these shares are growing rapidly because of issues like energy security, rising fossil fuel prices and, last but not least, global warming concerns and greenhouse gas reduction policies. Liquid transport fuels from biomass represent one of the most important options for the sustainable supply of transport fuels *(Kampman et al., 2010).*

Availability of land for non-food crops will be determined by increased yield potential, reducing losses and wastes along the food chain and lower inputs. However, these volumes will remain limited relative to total energy and transport sector fuel demand. Limited biomass resources will be allocated to the sector (materials, chemicals, energy) that is most able to afford them. This will depend on the price of existing fossil fuel products and the relative cost of converting biomass into substitute final fuels such as bio-derived electricity, ethanol blends, biodiesel and bio-derived jet fuel. It will also depend on factors such as cost of alternative fuel and energy sources, government policies including excise rates, and the emission intensity of each sector.

The sustainable use of residues and wastes for bioenergy, which do not require any new agricultural land and present limited or zero environmental risks, needs to be encouraged and promoted globally. Several factors may discourage the use of these "lower-risk" resources. Using residues and surplus forest growth, and establishing energy crop plantations on currently unused land, may prove more expensive than creating large-scale energy plantations on arable land. In the case of residues, opportunity costs can occur, and the scattered distribution of residues may render it difficult in some places to recover them *(IEA, 2010).* Whatever is actually realised will depend on the cost competitiveness of bioenergy and on future policy frameworks, such as greenhouse gas emission reduction targets.

4.2.2. Biofuels

The transport sector is responsible for about 20% of world primary energy demand (94 EJ). Transport biofuels are currently the fastest growing bioenergy sector. However, today they represent just 3% (2.4 EJ) of total road transport fuel consumption and only 5% of total bioenergy (in energy value). Liquid biofuels for transport are generating the most attention and have seen a rapid expansion in production. World fuel ethanol production amounted to 1.8 EJ and biodiesel production increased to 0.6 EJ in 2010. Liquid biofuels make a small but growing contribution to fuel usage worldwide. In 2010 they covered about 3% (2.4 EJ) of global road transport fuel consumption.

Currently, around 80% of the global production of liquid biofuels is in the form of ethanol. In 2012 global fuel ethanol production reached 86 billion liters, global biodiesel production amounted to 18 million tons, or 20 billion liters (*Figure 4 and Figure 5)*. In 2012 the United States was the world's largest producer of biofuels, followed by Brazil and the European Union. Despite continued increases in production, growth rates for biodiesel slowed again, whereas ethanol production growth picked up new momentum.

4.2.3. Transport policies

The passenger vehicle fleet will double to 1.7 billion in 2035. Common policies include biofuel subsidies, tax exemptions, blending mandates and the introduction of flex-fuel vehicles (FFV) Blending mandates, targets, fuel-tax exemptions and production subsidies exist in around 50 countries. City and local governments around the world continue to enact policies to reduce greenhouse gas emissions and promote renewable energy *(IPCC, 2011).*

To drive development of biofuels that provide considerable emission savings and at the same time are socially and environmentally acceptable, support measures need to be based on the sustainable performance of biofuels. Recent years have also seen increased attention to biofuels sustainability and environmental standards *(Licht, 2013).* Another approach is to directly link financial support to life-cycle CO_2-emission reductions (calculated with a standard life-cycle analysis methodology agreed on internationally) to support those biofuels that perform best in terms of CO_2 savings. Neither specific advanced biofuel quota, nor performance based support measures on their own seem to be effective to address the higher production costs of advanced biofuels in the short term. Specific transitional measures may thus be needed to support the introduction of the new technologies. Financial incentives, for instance a tax incentive or perhaps analogous to feed-in tariffs for electricity, could be coupled to the use of co-products such as waste heat to promote efficient use of by-products.

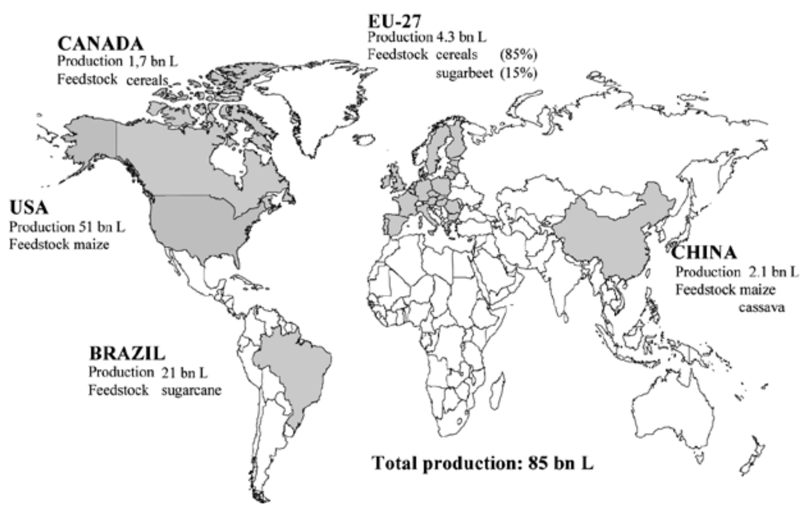

Figure 4: Word fuel ethanol production, 2012.
Source: Licht, 2013

Figure 5: World biodiesel production, 2012.
Source: Licht, 2013

4.3. Risks to the environment

4.3.1. Land use change and GHG emission

About 84% of current CO_2 emissions are energy-related and about 65% of all greenhouse-gas emissions can be attributed to energy supply and energy use. All sectors (buildings, transport, industry and other) will need to reduce dramatically their CO_2 intensity if global CO_2 emissions are to be decreased by 50 to 85% below 2000 levels by 2050. Energy-related carbon-dioxide (CO_2) emissions in 2010 are estimated to have climbed to a record 30.6 Gigatons (Gt) and concentrations have continued to grow to over 390 parts per million (ppm) CO_2 or 39% above pre-industrial levels. The Cancun Agreements call for limiting global average temperature rises to no more than 2 °C above pre-industrial values. In order to be confident of achieving an equilibrium temperature increase of only 2 °C to 2.4 °C, atmospheric GHG concentrations would need to be stabilized in the range of 445 to 490 ppm CO_2 equivalent in the atmosphere. Scientists warn that if the current trend to build high-carbon generating infrastructures continues, the world's carbon budget will be swallowed up by 2017, leaving the planet more vulnerable than ever to the effects of irreversible climate change *(Berndes et al., 2010).*

The transport sector is currently responsible for 23% of energy-related CO_2 emissions. To achieve the projected target of 50% reduction in energy-related CO_2 emissions by 2050 from 2005 levels sustainably produced biofuels production must provide 27% of total transport fuel. Reductions in transport emissions contribute considerably to achieving overall targets. India and China show significant increases because of rapidly growing vehicle fleets. Vehicle efficiency improvements account for one-third of emissions reduction in the transport sector; the use of biofuels is the second-largest contributor, together with electrification of the fleet accounting for 20% (2.1 Gt CO_2-equivalent) of emissions saving *(Berndes et al., 2010).*

Bioenergy's contribution to climate change mitigation needs to reflect a balance between near-term GHG targets and the long-term objective to hold the increase in global temperature below 2 ºC. Bioenergy has significant potential to mitigate GHGs if resources are sustainably developed and efficient technologies are applied. The impacts and performance of biomass production and use are region- and site-specific. Most current bioenergy systems, including liquid biofuels, result in GHG emission reductions, and advanced biofuels could provide higher GHG mitigation. The GHG balance may be affected by land use changes and corresponding emissions and removals.

The role of bioenergy systems in reducing GHG emissions needs to be evaluated by comparison with the energy systems they replace using life-cycle assessment (LCA) methodology. The precise quantification of GHG savings for specific systems is often hampered by lack of reliable data. Furthermore, different methods of quantification lead to variation in estimates of GHG savings. Nonetheless practically all bioenergy systems deliver large GHG savings if they replace fossil-based energy and if the bioenergy production emissions – including those arising due to land use change – are kept low. Currently available values indicate a high GHG mitigation potential of 60–120%[3], similar to the 70–110% mitigation level of sugarcane ethanol and better than most current biofuels *(IEA Bioenergy, 2009).* However, these values do not include the impact of land use change (LUC)[4] that can have considerable negative impact on the lifecycle emissions of advanced biofuels and also negatively impact biodiversity.

Biomass for energy is only one option for land use among others, and markets for bioenergy feedstocks and agricultural commodities are closely linked. Thus, LUC effects which are "indirect" to bioenergy are "direct" effects of changes in agriculture (food, feed), and forestry (fiber, wood products). They can be dealt with only within an overall framework of sustainable land use, and in the context of overall food and fiber policies and respective markets. The direct LUC effects of bioenergy production can, in principle, be controlled through certification systems, wherever biomass is grown. The risks of land-use change and resulting emissions can be minimised by focusing on wastes and residues as feedstock; maximising land-use efficiency by sustainably increasing productivity and intensity and chosing high-yielding feedstocks; using perennial energy crops, particularly on unproductive or low-carbon soils; maximising the efficiency of feedstock use in the conversion processes; cascade utilisation of biomass, i.e. linking industrial and subsequent energetic use of biomass; co-production of energy and food crops.

Changes in land use, principally those associated with deforestation and expansion of agricultural production for food, contribute about 15% of global emissions of GHG. Currently, less than 3% of global agricultural land is used for cultivating biofuel crops and LUC associated with bioenergy represents only around 1% of the total emissions caused by land-use change globally most of which are produced by changes in land use for food and fodder production, or other reasons *(Thrän et al., 2012).* Indirect land-use changes, however, are more difficult to identify and model explicitly in GHG balances. Most current biofuel production systems have significant reductions in GHG emissions relative to the fossil fuels displaced, if no indirect LUC effects are considered.

The bioethanol share in total grains demand in 2010 was 8%. By adding the feed value of ethanol by-product dried distillers's grains and soluable (DDGS), the net shares decline by one third to slightly above 5%. The fuel ethanol sector, mainly in the US, accounted for 16% (net 11%) of global corn consumption and 20% of global sugar cane production. The biodiesel share in rapeseed, soybean and palm oil demand was around 10% of global vegetable oil production. The share of waste biodiesel feedstocks such as animal fat and used

[3]An improvement higher than 100% is possible because of the benefits of co-products (notably power and heat).

[4]Two types of land use change (LUC) exist: direct LUC occurs when biofuel feedstocks replace native forest for example; indirect LUC (iLUC) occurs when biofuel feedstocks replace other crops that are then grown on land with high carbon stocks.

cooking oil increased to 15% in total biodiesel output in 2010 (*Licht, 2013*).

In 2010 about 20 million gross hectares of grains, sugar cane and cassava for fuel ethanol production and 20 million gross hectares of oilseed feedstock was needed for biodiesel production (*Thrän et al., 2012*). The proportion of global cropland used for biofuels is currently some 2.5% with wide differences among countries and regions. The biofuel production processes give rise to by-products which are largely suitable as animal feed. By-products are supposed to be credited with the area of cropland required to produce the amount of feed they substitute. In the cases of grains and oilseeds, DDGS (dried distillers grains with solubles) and CGF/CGM (corn gluten feed/meal) and oil cakes (mainly rapeseed and soybean cake/meal) substitute grain and soybean as feed. It means that not all the grains used for ethanol production should be subtracted from the supplies since some 35% is returned to the feed sector in the form of by-products (mainly DDGS) so the land required for feedstock production declines to 15 million hectares. In case of biodiesel production 50-60% of rapeseed (rapeseed cake/meal) and 80% of soybean (soybean meal) is returned to the feed sector and the net land requirement decrease to around 6 million hectares. By adding by-products substituted for corn and soybean meal the net hectares needed for fuel ethanol decline to 21 million (authors' calculation). By adding by-products substituted for grains and oilseeds the land required for cultivation of feedstocks declines to 1.5% of the global crop area (net land requirement).

Based on the land-use efficiencies land use for biofuel production would need to increase from 40 million hectares (21 million hectares net land requirement by adding by-products substituted for grains and oilseeds) to around 100 million hectares in 2050. This corresponds to an increase from 2.5% of total arable land today to around 6% in 2050. This expansion would include some cropland, as well as pastures and currently unused land, the latter in particular for production of lignocellulosic biomass (*IEA, 2010*).

4.3.2. Sustainability criteria for bioenergy

Many efforts are under way to develop sustainability criteria and standards that aim to provide assurance about overall sustainability of biofuels. International initiatives include the Global Bioenergy Partnership, the Roundtable on Sustainable Biofuels, the International Organization for Standardization and the International Sustainability and Carbon Certification System. There are also initiatives looking at standards for the sustainable production of specific agricultural products, such as the Roundtable for Sustainable Palm Oil, the Roundtable for Responsible Soy and the Better Sugarcane Initiative. Development of standards or criteria will push bioenergy production to lower emissions and higher efficiency than today's systems. The standards aim at ensuring sustainable production of feedstocks, regardless of their final uses (be it for food, material or biofuel production), and can thus help to ensure sustainable production throughout the whole sector, rather than for the feedstock specifically dedicated to biofuel production. Some policies have been adopted during recent years that include binding sustainability standards for biofuels.

Some of the GHG emissions principles require process improvement over time, while others require a specific target to be achieved. Some schemes require higher emission treshholds over time. The EU is the global frontrunner on sustainability, other continents may follow. The EU has introduced regulations under the RED (Renewable Energy Directive) that lay down sustainability criteria that biofuels must meet before being eligible to contribute to the binding national targets that each Member State must attain by 2020 (*Official Journal of the European Union, 2009*). In order to count towards the RED target, biofuels must provide 35% GHG emissions saving compared to fossil fuels. This threshold will rise to 50% as of 2017, and to 60% as of 2018 for new plants. However, there is a loophole as only direct LUC emission is accounted and indirect LUC emission is not calculated. The difficulty is that indirect LUC cannot be observed or measured.

The RED promotes advanced biofuels (biofuels from lignocellulose, algae, wastes and residues), by counting their contribution twice towards the 2020 target. Each Member State has adopted a certification system but there is no EU-wide alignment. As a consequence most of the Member States have not yet (fully) transposed the RED, e.g. double counting mechanism or defining highly bio-diverse grasslands. Harmonised definitions of waste, residues and highly bio-diverse grasslands are needed to avoid market distortion and make the voluntary sustainability schemes work. The full and harmonized transposition of the RED by the Member States is important for the future development of the industry. Critical issues around the double counting mechanism and indirect LUC need also to be resolved in a timely manner.

In the United States, the Environmental Protection Agency (EPA) is responsible for the Renewable Fuel Standard program. This establishes specific annual volume requirements for renewable fuels, which rise to 36 billion gallons by 2022. These regulatory requirements apply to domestic and foreign producers and importers of renewable fuel used in the US. Advanced biofuels and cellulosic biofuels must demonstrate that they meet minimum GHG reduction standards of 50% and 60% respectively, based on a life-cycle assessment (including indirect land-use change) in comparison with the petroleum fuels they displace. In 2010, the EPA designated Brazilian sugarcane ethanol as an advanced biofuel due to its 61% reduction of total life cycle greenhouse gas emissions, including direct indirect land use change emissions. In Switzerland the Federal Act on Mineral Oil mandates a 40% GHG reduction of biofuels in order to qualify for tax benefits.

Sustainability criteria and biomass and biofuels certification have been developed in increasing numbers in recent years as voluntary or mandatory systems; such criteria, so far, do not apply to conventional fossil fuels. The registered several dozens of initiatives worldwide to develop and implement sustainability frameworks and certification systems for bioenergy and biofuels, as well as agriculture and forestry, can lead to a fragmentation of efforts. A proliferation of standards increases the potential for confusion, inefficiencies in the market and abuses such as “shopping” for standards that meet particular criteria. There is a risk that different and partially incompatible systems will create trade barriers. Lack of international systems may cause market distortions (*van Dam et al., 2010*). Production of ”uncertified” biofuel feedstocks will continue and enter other markets in countries with lower standards or for non-biofuel applications that may not have the same standards.

5. Conclusion

The increased population density, coupled with changes in dietary habits in developing countries towards high quality food is projected to increase demand for food production by 60% by 2050. In addititon unprecedented development is taking place, especially in areas that have traditionally had very low per capita demand on fossil resources. The need to increase agricultural productivity and efficiency in developed as well as in developing countries is now widely accepted. Producing more food sustainably requires crops that make better use of limited resources including land, water and fertiliser. With increasing demands of energy it has become apparent that the continued emissions of greenhouse gases and loss of carbon sinks are influencing the world climate.

The main strategy proposed to ameliorate the effects of climate change is to reduce global demand for fossil fuel resources. A constant and renewable supply of energy that has a low carbon cost is required. The contribution of bioenergy to improving energy security largely depends on decoupling the bioenergy system from oil and gas inputs. In many countries, stronger climate change and environmental directives have become an impetus for the accelerated development of renewable energy supply. But the recent expansion of the bioenergy industries together with a strong increase in many commodity prices has raised concerns over the land use choices between energy needs and food and feed.

The worldwide potential of bioenergy is limited, because all land is multi-functional and land is also needed for food, feed, timber and fiber production, and for nature conservation and climate protection. In addition, the use of biomass as an industrial feedstock (e. g. plastics) will become increasingly important. As future yield increases are uncertain the highest priority should be given to the use of organic waste, harvest wastes and residues, since the associated risks are minimal, because it does not require any new agricultural land. If, however, energy crops are cultivated, they should where possible be grown on previously unused, degraded land. This promotes nature conservation and climate change mitigation and helps prevent risks to food security. Availability for non-food crops will be determined by increased yield potential, reducing losses and wastes and lower inputs. In addition, competition for the best use of biomass (materials, chemicals, energy) has also to be taken into consideration. How will biomass resources be allocated depends on costs associated with biomass storage, transportation, and economic and environmental consideration. Biorefineries can make a significant contribution to sustainable development by adding value to the sustainable use of biomass. They can produce a spectrum of bio-based products (food, feed, materials, biochemicals) and bioenergy (fuels, power and/or heat) feeding the full bio-based economy.

The international bioenergy market is expected to have a wide range of suppliers from several world regions and the importation of bioenergy is therefore not affected by the same geopolitical concerns as are oil and natural gas. The use of bioenergy resources and biomass trade would generally contribute to the diversification of the energy mix. A regime for the growing trade of solid biomass (pellets, chips) and liquid biofuel is needed with the adoption of sustainability criteria in the international arena. A trend toward harmonisation of standards and certificates can be expected to continue in the future, however, the number of standards is continuously changing to take in to account the scientific advancaments in the design and production of new materials and ever changing applications.

The increasing demand for suitable land in which this biomass needs to grow competes with the need for food production. This is causing conflicts between land use for food and those for producing bioenergy crops. These problems will be amplified by the change in land productivity caused by climate change (erosion, water stress, increasing soil salinity, and others more). Policies for promoting biomass as an alternative energy source will need to take these potential land use conflicts into account. The global potential for biomass energy production is large in absolute terms, but it is far not enough to replace the current energy usage. Increasing biomass energy production beyond a certain level would have significant effects on land use and conventional agricultural markets. Conflicts resulting from limited land need to be solved by R&D support and efficient regulation on an international level if biomass is supposed to increase its share of the energy mix.

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