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André Faaij:

Bioenergy and global food security

**Externe Expertise für das WBGU-Hauptgutachten
"Welt im Wandel: Zukunftsfähige Bioenergie und
nachhaltige Landnutzung"**

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Bioenergy and global food security.

A paper prepared for the German Advisory Council on Global Change¹.

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1. Introduction

We face an unprecedented situation for our planet and mankind. It is expected the global population will peak around 9 billion people around 2050. That same population, despite huge inequalities, is richer than ever in history, creating peak demand for energy, food, water, space and every natural resource imaginable. The results are known: climate change, rapid loss of biodiversity (partly because of climate change), increased pressure on water resources, large scale pollution...

All these matters are coming to a peak during this century. It is still thought that this climax can be succeeded by a period in which pressures on the environment and earth's ecosystem would gradually decrease. (IPCC, 2007, Millennium Ecosystem Assessment, IUCN, 2003).

Global energy demand is growing rapidly. The total current commercial energy use amounts some 470 EJ. About 88% of this demand is covered by fossil fuels. Energy demand is expected to at least double or perhaps triple during this century.

At the same time, concentrations of greenhouse gases (GHG) in the atmosphere are rising rapidly, with fossil fuel bound CO₂ emissions being the most important contributor. In order to stabilize related global warming and climate change impacts, GHG emissions must be reduced drastically to less than half the global emission levels of 1990. In addition, security of energy supply is fully back on the agenda as a global issue. Supplies of conventional oil and gas reserves are increasingly concentrated in politically unstable regions and increasing the diversity in energy supplies is important for many nations to secure a reliable and constant supply of energy.

To reverse these trends to what may be called a sustainable development pathway, a wide range of major transitions is needed: first of all energy systems and 'tackling' climate change is necessary by massive improvement of energy efficiency and a shift to renewable energy sources. Second, agriculture worldwide requires a new 'green revolution' to absorb the growing demand for food (and in particular protein) and at the same time lower pressure on available lands and natural resources (such as water). This requires large scale improvement in agriculture towards sustainable practices and more efficient management. Linked to this is fighting poverty. 70% of the world's poor live in rural areas.

Many more shifts are needed; e.g. with respect to protection of biodiversity, sustainable management of soils and water resources. With respect to energy, a secure and stable supply that is also affordable is a prerequisite for sustainable development, in particular again for LDC's.

In this global context, it is suggested that the use of biomass for energy (as well as material) can play a pivotal role. Biomass use for energy, when produced in a sustainable manner, can drastically reduce GHG emissions compared to fossil fuels. Most countries have various biomass resources available or could develop a resource potential, making biomass a more evenly spread energy supply option across the globe. It is a versatile energy source, which can be used for producing power, heat, liquid and gaseous fuels and

¹ This paper is prepared as a background and resource document for the flagship report "Bioenergy and sustainable land use" of the German Advisory Council on Global Change (WBGU). It is based on a compilation of available texts and recent work in which author was involved as researcher, (co-)author, coordinator or reviewer. In addition some recent work of FAO is used. Key publications used are: (Dam et al., 2008), (Dornburg, Faaij et al., 2008a), (Dornburg, Faaij et al., 2008b), (Fresco, 2006), (Cramer et al., 2007), (Best et al., 2008), (Schmidhuber, 2006).

also serves as carbon neutral feedstock for materials and chemicals. Especially due to rising prices for fossil fuels (especially oil, but also natural gas and to a lesser extent coal) the competitiveness of biomass use has improved considerably over time. In addition, the development of CO₂ markets (emission trading), as well as ongoing learning and subsequent cost reductions for biomass and bioenergy systems, have strengthened the economic drivers for increasing biomass use, production and trade. Biomass and bioenergy has become a key option in energy policies. Security of supply, an alternative for mineral oil and reduced carbon emissions being key reasons. Targets and expectations for bioenergy in many national policies and long term energy scenario's are ambitious, reaching 20-30% of total energy demand in various countries, as well as worldwide.

Currently about 45 + 10 EJ of global energy demand is provided by biomass resources, making biomass by far the most important renewable energy source used to date. On average, in the industrialized countries biomass contributes less than 10% to the total energy supplies, but in developing countries the proportion is as high as a fifth to one third. In quite a number of countries biomass covers even over 50 to 90% of the total energy demand. A considerable part of this biomass use is however non-commercial and used for cooking and space heating, generally by the poorer part of the population. Part of this use is commercial though, i.e. the household fuel wood in industrialized countries and charcoal and firewood in urban and industrial areas in developing countries, but there are almost no data on the size of those markets. An estimated 9 + 6 EJ is covered by this category.

Modern bio-energy (commercial energy production from biomass for industry, power generation or transport fuels) makes a lower, but still very significant contribution (some 7 EJ/yr in 2000), and this share is growing. It is estimated that by the end of the nineties, some 40 GWe biomass based electricity production capacity was installed worldwide (good for some 0.6 EJ electricity per year) and 200 GW heat production capacity (some 2.5 EJ heat per year). Biomass combustion is responsible for over 90% of the current production of secondary energy carriers from biomass. Combustion for domestic use (heating, cooking), waste incineration, use of process residues in industries and state-of-art furnace and boiler designs for efficient power generation all play their role in specific contexts and markets. Total production of biofuels for transport (mainly ethanol produced from sugar cane and surpluses of corn and cereals and to a far lesser extent bio-diesel from oil-seed crops) represent a modest 1.5 EJ (about 1.5%) of transport fuel use worldwide . But it is especially in this field that global interest is growing, in Europe, Brazil, North America and Asia (most notably Japan, China and India). [WEA, 2000 / 2005 + IEA/WEO, 2006]. Global ethanol production has more than doubled since 2000, while production of biodiesel, starting from a much smaller base, has expanded nearly threefold. In contrast, crude oil production has increased by only 7 percent since 2000.

However, the recent booming interest, in particular in biofuels, goes hand in hand with growing concerns, which are the same order of magnitude as the, perceived, advantages of bioenergy. Food prices have risen sharply over the past years and biofuels are pinpointed by many to be the cause of that, a key factor being the subsidized production of biofuels in the European Union and the United States, which is even with the current oil prices not competitive. The use of palmoil (of which some 1.5% of production was used for biodiesel and fuel for electricity production in 2007) is held responsible for the loss of the tropical rainforest in South East Asia where production is concentrated. Palmoil, but also corn for ethanol and other biofuels from food crops are therefore not neutral with respect to greenhouse gas emission at all. On the contrary, some emit more GHG's than their fossil counterparts. Biofuels will cause massive starvation, deplete water resources, destroy biodiversity and soils as stated by various people as Ziegler, Monbiot a.o. This seems a massive collision of ideals and the real world. How is such a contrast possible? It seems that biomass is a very attractive option for both the chemical industry and for energy, but if the resources are not there or if can by far not be called sustainable, where is than the foundation for the future biobased economy?

Due to the nature of bioenergy, developments in the bioenergy sector are closely linked to food security. Furthermore, as bioenergy demand increases, agriculture also has to provide for growing food and feed demand due to population and economic growth.

In theory, many developing countries have very large land areas and human resources available for bioenergy production. However, the production of biomass required to supply significant shares of national and global energy provision, from energy crops needs to be substantial. This will result in significant impacts on ecosystems and socio-economic conditions, including food security. These impacts could be positive or negative depending on the local conditions. Hence, prior to deciding on the actual realization and sustainable implementation of bioenergy, it is crucial to understand the full range of net impacts of bioenergy schemes on food security issues.

The linkages between bioenergy and food security are complex. On the one hand biomass production competes with food production for land and other agricultural production factors. On the other hand, biomass production may contribute to rural development, for example by increasing local employment and energy supply. Thus, implementing bioenergy production in developing countries can lead to either an improvement or a deterioration in the food security conditions. The impacts of bioenergy developments on food security depend on many factors that are country and case specific. Examples of these factors are the type of biomass used, the type of energy carrier produced, the type of land for biomass production, developments in agricultural management and developments in the global food markets.

The objective of this paper is to explore the interlinkages between biomass production and use for energy and food security. Both conflict areas and possible synergies are highlighted. An overall view on the sustainable potential of bio-energy on longer term on global scale is given and the paper closes with a set of interlinked recommendations how such a sustainable pathway could be followed. This paper is compiled from recent state-of-the-art material in the field.

2. Bioenergy and food security

Food security exists when all people, at all times, have physical, social and economic access to sufficient amounts of safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. There are four dimensions to food security: availability, access, stability and utilization. Availability of adequate food supplies refers to the capacity of an agro-ecological system to meet overall demand for food (including animal products, livelihoods and how producers respond to markets). Access to food refers to the ability of households to economically access food (or livelihoods), defined in terms of enough purchasing power or access to sufficient resources (entitlements). Stability refers to the time dimension of food security. Stability of food supplies refers to those situations in which populations are vulnerable to either temporarily or permanently losing access to resources, factor inputs, social capital or livelihoods due to extreme weather events, economic or market failure, civil conflict or environmental degradation, and increasingly, conflict over natural resources. Utilization of food refers to peoples' ability to absorb nutrients and is closely linked to health and nutrition factors, such as access to clean water, sanitation and medical services.

Major linkages: prices and income

Key is how bioenergy production impacts on food security through changes in market based incomes and food prices. In many circumstances these are likely to be the quantitatively most important effects, however, there is no doubt that bioenergy production may have effects on food security that are not mediated by income and prices.

With regard to incomes and prices, it is obvious that income is a critical determinant of food security for the poor. The more income that a given household or individual has, the more food that can be purchased, both in terms of quantity and quality. Food prices are also important determinants, but the precise effects of food prices on food security are more complex. To determine the effects of food prices on food security, however, it is important to distinguish between net food producers and net food consumers.

Generally speaking higher food prices can substantially hurt net food consumers as is clearly observed in many countries today. On the other hand, farmers who are net food producers are likely to benefit from higher prices, which, other things being equal, will tend to increase their incomes. Thus, there will always

be some people for whom food security improves, while others experience a deterioration in food security. The exact net outcome will depend on the socio-economic structure of society, as well as on the specific commodities whose price increases, and the relative position in the income distribution of the farmers who produce the commodities that have experienced the price increase. For example, poor farmers might be net producers of a commodity whose price increased. At the same time, the farmer might also be a net consumer of commodities whose price increased. Therefore, a priori, the net effect on food security is not clearly determined, it may be positive or negative.

Competition for production inputs

Bioenergy production will nearly always compete for inputs with food production including feed². Inputs include land, labor, water and fertilizer. Food crops that are used for bioenergy production compete directly with food supplies. Moreover, the competition for inputs places upward pressure on food prices, even if the feedstock itself is a non-food crop or is grown on previously unused land. On the contrary, improved bioenergy production systems that allow for synergies with food production exist. For example, intercropping of jatropha with annual food crops can potentially increase food yields, while at the same time producing biomass for energy. Agroforestry systems can deliver both food and biomass for construction, fibre and fuel use, as well as secure high levels of biodiversity and there are many other examples.

Finally, the competition between bioenergy and food production for inputs depends on the developments in the agricultural sector and consequent variations in agricultural productivity. Higher prices for food products or strategies that stimulate policies for developments in agricultural management might lead to an increase in agriculture efficiency as the increased demand leads to higher investments in the agricultural sector. As a result, food production in the agricultural sector could improve using less of the resources at hand for the production of a given amount of bioenergy.

World market integration

As world commodity markets become more integrated, bioenergy production in one country will have important effects on food security in other countries as changes in food prices on international markets affect domestic markets. However, countries may prevent these effects on domestic markets by agricultural market policies related to trade and domestic prices. Moreover, self-sufficient areas that don't have access to markets can be excluded from these effects. The effect will depend on domestic trade policies and infrastructure. Bioenergy production may affect food security in small developing countries even if the country concerned is not involved in bioenergy production of its own. The effect is quite simple: higher prices on international commodity markets due to, for example, increased demand for corn as an ethanol feedstock in the United States, will in many cases spill into commodity markets in developing countries. Therefore, it is important to evaluate food security impacts of national bioenergy strategies against the background of global market developments. These spill-over effects are caused by the increased global demand on food commodities and the resulting increased prices on the world market. Without additional domestic policies, these world market prices translate to the domestic markets.

Environmental constraints in the scenarios

Environmental constraints can limit the biophysical and technical production of bioenergy and food. For example, water resources are a limiting factor of energy crop production. Moreover, environmental impacts can limit the type of bioenergy strategies considered in the country specific scenarios. For example, in a scenario where biodiversity conservation is a high priority, areas with high conservation value can be excluded from bioenergy and food production. Second, environmental impacts of bioenergy production as regarded in the scenario provide feedback that has an affect on the local environmental conditions. For example, if degraded land can be reclaimed by bioenergy production, this land area then becomes again available for agricultural production.

² In this context, food includes food from vegetable materials as well as food from animal products. As such, the use of feed to produce animal products is always implicitly included in the analysis of food.

The production of bioenergy leads to environmental impacts that can be higher or lower than the reference situation. Important environmental impacts that play a role in the definition of country-specific scenarios and that determine the potentials of bioenergy production are:

- **Net reduction of GHG emissions** of certain biomass supply chain compared to fossil energy chains is one of the criteria often used in sustainability schemes of biomass production and trade. GHG balance could be used as a parameter for scenario analysis.
- **Use of agrochemicals and fertilizers** in the production of biomass and food can negatively impact land productivity and water quality. However, an appropriate use of agrochemicals and fertilizers can increase crop yields. For example, if higher fertilizers levels than those required to meet crop nutrients are applied then the excess will be loss causing detrimental environmental impacts to surrounding water bodies. Therefore, levels of agricultural management influence the amount of biomass and food that can be produced in a sustainable way.
- **Water use** is an important factor in bioenergy production as water can be a limiting factor for biomass and food production in many regions of the world. Furthermore, water requirements differ among crop production schemes depending on their water efficiency. Moreover, sustainable irrigation practices and technologies can increase overall yields of crops for food and bioenergy production.
- **Soil quality** can be either positively or negatively affected by different crop production schemes and the level of intensity of livestock production. Thus, the use of land influences soil productivity in the long-term. For example, intensive agricultural practices can lead to deterioration on soil quality that translates into lower productivity. Consequently, lower productivity affects the availability of food resources. On the other hand, opportunities to produce perennial bioenergy crops in lands unsuitable for food production can contribute to the improvement of soil quality while at the same time expanding land availability for crop production.
- **Biodiversity** issues influence the amount and type of biomass that can be produced, for example, by excluding certain types of land from biomass production and by excluding certain management practices.

Labour markets

Biofuels production (either domestic or international) may have an effect on labour demand if new land is brought into cultivation or if cropping patterns on currently cultivated land change substantially. Changes in labour demand could affect rural wages, and these changes in wages would have an impact on the incomes of the poor. Data on the labour intensity of key crops used in the production of biofuels as well as similar data on crops whose production may decline as biofuels demand increases are important. This will allow an assessment of the labour intensity of different cropping patterns (with and without biofuels), which is crucial for understanding the net employment impact of biofuels demand. This should include the importance of agriculture wage income for poor households.

Price transmission

International price movements related to biofuels demand can be transmitted to domestic markets even in the absence of domestic biofuels production. But transmission of international prices to domestic prices depends on several factors: exchange rate movements, trade policy and infrastructure, to name a few. It is important to understand the nature of price transmission. If changes in international prices are not transmitted to domestic prices, this will eliminate one key channel through which bioenergy demand affects food security.

3. Food Demand

Population growth has been responsible for 80% of the increase in food consumption between 1970 and 1998 and probably will remain the key driver of increasing food consumption during the coming decades [FAO, 2004]. The United Nations Population Division (UNPD) has become the main authority in this field and UNPD projections are commonly used in outlook studies, see e.g., [FAO, 2007, IFPRI, 2001]. UNPD data are also used in this study; data are available at a country level and summed up into regional totals [UNDP, 2003].

There is general agreement among demographers that population projections, if properly made, are ‘fairly accurate for some 5–10 years’ [Heilig, 1996]. The reason is that the number of children that will be born within this period depends on the number of young adults in a population and this number is known from statistics. This effect is called the population momentum. Long-term population projections have proven to be more uncertain [Heilig, 1996], particularly for developing regions. For example, the forecast error in predicting the world population for the year 2000 was +0.5% for projections done in 1996, +3.3% for projections done in 1990, and 7.1% for projections done in 1968 [IFPRI, 2001].

To reflect this uncertainty, the UNPD distinguishes six scenarios for the development of population of which the low, medium and high scenario are used in our model. The low and high scenarios are derived from the medium scenario: the fertility rate is set at 0.5 child below and above the medium fertility rate, respectively [UNDP, 2003]. Although there is no clear scientific basis for this assumption, the low and high scenarios represent a bandwidth within which population might develop. No distribution of probability is presented for the various scenarios. The medium growth scenario may be considered the most likely scenario and is for that reason frequently used in outlook studies¹⁶ (e.g., [FAO, 2003]). It should be noted that the uncertainty related to population projections seems to have increased during the previous decade: projections have been downward adjusted considerably, in total more than 10% during the last decade, partially because the impact of AIDS is evaluated to be more severe than earlier expected [UNDP, 2003].

Per capita demand for food

During the last decades the average food intake per capita has steadily increased in most regions: on average from about 2360 kcal cap₁ day₁ in the mid 1960s to 2798 kcal capita₁ day₁ in 2002 [FAO, 2003]. This progress mainly reflects the increase in consumption in the developing countries, because consumption levels have reached saturation levels in the industrialized regions.

Projecting the consumption of food requires the matching of demand and supply. Projections of the FAO for the years 2015 and 2030 are generally used. Together with projections from the International Food Policy Research Institute (IFPRI) [IFPRI, 2001] and the United States Department of Agriculture (USDA); e.g., [USDA, 2004] these are the most detailed projections available. The USDA and the IFRPI projections referred to above go to 2013 and 2020 only, respectively. Therefore, the FAO projections are used in our study. The per capita food consumption in 2030 is calculated by multiplying the food intake per capita in 1998 (in t yr₁ cap₁) derived from the FAOSTAT database [FAO, 2003] by the relative increase in the per capita consumption projected by the FAO. Fourteen food product groups are included: cereals, roots and tubers, sugar crops, pulses, oil crops, vegetables, stimulants, spices and alcoholic beverages, bovine meat, mutton and goat meat, pig meat, poultry meat and eggs and milk. Consequently, changes in food consumption between the different product groups are included.

Here, the projections to 2030 were trend extrapolated to 2050 and the results of the trend extrapolation were down or upscaled using data from other sources [IMAGE, 2001, IFPRI, 2001]. For East Asia and South Asia trends were downscaled, because the rapid economic growth projected for the coming decades is assumed to flatten off in the longer term. The trend was upscaled for sub-Saharan Africa, because the slow economic growth projected for the near future is assumed to increase in the longer term. The consumption was however not allowed to increase above 3700 kcal cap₁ day₁, of which 1100 kcal cap₁ day₁ animal products (including fish and seafood). This level was taken as saturation level, because consumption in the industrialized countries is stabilizing at this level, despite increases in income.

The consumption of food is projected to increase from 2739 kcal cap₁ day₁ in 1998 to 3302 kcal cap₁ day₁ in 2050. The average daily calorie intake in 2050 in the developing countries, transition economies

countries, and industrialized countries was calculated at 3236, 3448, and 3629 kcal cap⁻¹ day⁻¹, respectively, of which 549, 941, and 1054 kcal cap⁻¹ day⁻¹ from animal products (including fish and seafood), respectively. The increase in the industrialized regions is limited, because consumption reached saturation levels in these regions. In the transition economies, consumption decreased considerably after the collapse of communism and the following economic restructuring. It may take several decades before consumption levels have reached their former levels. In the developing regions consumption increases rapidly, particularly in Asia. The consumption in sub-Saharan Africa is also projected to increase, although at a slightly lower rate, due to slower income growth compared to Asia. These data indicate that considerable differences in food intake remain present the coming decades, particularly with respect to the intake of animal products.

Vegetal products account for about three-fourth of the increase in the global average food consumption projected for 1998–2050; the remaining one-fourth comes from animal products (including fish and seafood). However, in relative terms the consumption of animal products is projected to increase faster than the consumption of vegetal products: the per capita consumption of vegetal products and animal products is projected to increase by 16% and 38%, respectively. Consequently, the share of animal products as percentage of the daily kcal intake increases.

The increasing demand for animal products is expected to have a large impact on the world food economy and that has therefore been referred to sometimes as the ‘food revolution’ or ‘livestock revolution’ [Delgado, 1999].

Consumption levels in many developing regions may remain well below saturation levels in 2050 and consequently undernourishment may not be eradicated in the projections. Consumption in these regions is responsive to further increases in income or decreases in food prices compared to industrialized regions where saturation levels have nearly been reached. Small changes in GDP or prices may significantly increase consumption in developing regions, which means that projections for these regions are more uncertain.

Undernourishment

Till recently, the FAO, the IFPRI and the USDA are moderately positive on the global food security situation, meaning that the supply is expected to increase at the same rate as demand and that the average per capita food consumption will remain stable or increase in all regions. Yet, undernourishment will most likely remain to exist during the coming decades: the number of undernourished people is projected to decrease from 815 million in 1990, to 610 million in 2015, and 440 million in 2030 [FAO, 2003].

The Millennium Development Goal (MDG; to halve the number of undernourished between 1990 and 2015) is not likely going to be met, unless additional activities are undertaken other than included in the FAO projections

Food production and food security must be given priority above energy crop production. However, this does not mean that the production of dedicated bioenergy crops should be banned in case undernourishment exists in a region. In reality, food insecurity is the result of a number of factors, including war, civil unrest and unequal distribution of income, rather than a lack of cropland. Further, the production of energy crops may provide new opportunities for farmers to generate income and diversify agricultural production. Diversification enhances resilience and flexibility with respect to changes in yields and prices, and also reduces the dependence on conventional cash crops of which the production and export is often hampered by saturated markets and trade barriers.

Technologically speaking, producing enough food for even 10 billion people seems feasible (Evans, 1998). In contrast, doing so without compromising sustainability – both by pollution and by resource depletion – will be a formidable challenge (Tilman et al., 2002). Currently, *food production* appropriates about 75% of the available freshwater and 35% of the global land area (Smil, 2002a: 239). While the world population doubled during the second half of the 20th century, in consequence of increasing incomes, its appetite for meat quadrupled, requiring 40-50% of the world grain harvest to be fed to livestock (Evans, 1998). Within the food domain, meat production has a disproportionate environmental impact (Aiking et al., 2006) and, therefore, environmental impacts of food production are strongly coupled to actual diets.

In striving for sustainable food production and consumption, the protein chain is an excellent starting point (Grigg, 1995; Millstone and Lang, 2003; Smil, 2002b), as on average, 6 kg of plant protein is required to yield 1 kg of meat protein [Pimentel and Pimentel, 2003; Smil, 2000). In theory, a promising solution may be offered by partial replacement of meat proteins with plant protein products (so-called Novel Protein Foods, NPFs) in the human diet. We estimate, conservatively, that - without putting a healthy nutrition in jeopardy - world meat supply could easily be cut by *one third*, i.e. from 140-166 to 100%. Even then, our average protein consumption would be 20% over the RDI (recommended daily intake) and one third of our protein consumption would still be derived from meat. Life cycle assessment showed that a partial transition from animal to plant protein (abolishing feed production but keeping extensive livestock, i.e. feeding on grass and agricultural waste) might result in a 3-4 fold lower requirement of agricultural land and freshwater to start with. Moreover, world wide there is potential for a 30-40 fold reduction in water use (Aiking et al., 2006). Several economic arguments (Seidl, 2000; White, 2000) indicate, however, that actual practice may be not as straightforward as theory suggests, due to status and cultural trends.

The principal food demand projections are those by the FAO, which are based on supply (production + imports - exports) per country, per commodity. They are the best available, but the descriptive data is crude and so are the projections based on them. The largest knowledge gap in the available models and data is probably in consumer preferences. Studies of diet change show that in addition to availability and price, status aspects and cultural trends play an important role.

4. Key concepts for food security.

Some 70 percent of the 854 million hungry people in the world live in rural areas and depend on agriculture, often concentrated in regions that are particularly vulnerable to environmental degradation and climate change. An estimated 820 million are in developing countries, 25 million in countries in transition, and 9 million in industrialized countries. Hunger claims up to 25,000 lives every day, two thirds of them children under the age of five, and is currently the leading threat to global health, killing more people than AIDS, malaria, and tuberculosis combined. Although the proportion of undernourished in the world has declined from 20 percent to 17 percent since the mid-1990s, the absolute number of hungry people has remained the same. Global progress towards halving the proportion of hungry people by 2015 remains slow and largely uneven. Only Latin America and the Caribbean, amongst developing regions, have reduced the prevalence of hunger at a rapid enough pace to reach the Millennium Development Goals (MDG) target.

Country typologies

Growth rates of agricultural production and consumption in developing countries have outpaced those of industrialized economies in recent years. This has not been the case, however, for most of the Least Developed Countries (LDCs), where agricultural output has not kept pace with population growth and increased domestic demand. Preliminary analysis of the impact of bioenergy on food security should thus highlight differences between developing, least developed, and low-income food deficit countries (LIFDCs). These two latter groups are typically the most food insecure, given high dependence on staple food imports and exports of primary tropical commodities.

LDCs have the highest proportion of chronically undernourished populations, and have become increasingly reliant on imports of basic commodities to ensure food security. For many, this has also resulted in increased exposure to international market price fluctuations, increasing overall food insecurity. Further development of bioenergy systems will increasingly highlight the direct linkages between food security and energy security. These linkages function as an additional source of uncertainty in global production and marketing systems; markets that are already more susceptible to greater variability in pricing and production due in part to trade liberalization and structural adjustments in food and agricultural sectors. Natural disasters and lack of productive input factors, such as fertilizer or water resources, also constrain or result in lost agricultural output, and lowers overall food availability.

The competition for more arable land and water resources directed to biofuel production may lead to higher and less stable food prices, for countries that are both net food importers and exporters. This may be particularly true for low-income, food deficit countries (LIFDCs) that already have a large proportion of undernourished and are net importers of basic foods, and may face serious problems of food access within vulnerable populations. Poor households tend to spend a larger proportion of income on food than other items, including energy, and thus, may be particularly challenged by rising food prices, globally and locally.

Linkages between prices, biofuels and food security

Current and expected trends in energy prices may catalyse further growth in bioenergy production and more rapid adoption of bio-based fuels. Biofuels represent an important and growing source of demand for agricultural commodities. Recent FAO research notes that prices for fossil fuels may essentially establish floor and ceiling prices for agricultural commodities used as feedstock.

Major producers of biofuels, such as Brazil, the United States, the EU and Canada are either expected to reduce exports of basic feedstock commodities (cereals or oilseeds) and increase biofuel imports. This can have serious economic, environmental and food security implications for many developing countries, particularly countries that have large proportions of poor food insecure people living in rural areas. Agricultural commodity prices have long been influenced by energy prices, because of the importance of fertilizers and machinery as inputs in commodity production processes. The possibility of increased competition for agricultural, water and other natural resources for bioenergy systems instead of food production is already evident. However, given potentially significant markets for bioenergy, competition for resources could induce result in price increases that adversely affect the ability of lower income consumers to purchase food.

Rising commodity prices, while beneficial to producers, will mean higher food prices with the degree of price rise depending on many factors including, as mentioned, energy prices, with negative consequences for poor consumers. Expanded use of agricultural commodities for biofuel production will strengthen this price relationship and could increase the volatility of food prices with negative food security implications. Developing guidelines to analyse how bioenergy can contribute to rural development, as well as formulate policy to ensure that the food security concerns of the rural poor, particularly female smallholders and household heads, is vitally important to ensure that the outcomes of rapid bioenergy development are positive.

Countries with 20 to 34 percent of the population considered undernourished include Bangladesh, Bolivia, Botswana, Cambodia, Cameroon, Chad, Congo, Dominican Republic, Gambia, Guatemala, Guinea, Honduras, India, Kenya, Laos Peoples Democratic Republic, Malawi, Mali, Mongolia, Namibia, Nicaragua, Niger, Pakistan, Panama, Senegal, Sri Lanka, Sudan, Thailand, Togo.

Countries with more than 35 percent of the population considered undernourished include Angola, Burundi, Central African Republic, Chad, Democratic Republic of the Congo Democratic People's Republic of Korea, Eritrea, Ethiopia, Haiti, Liberia, Madagascar, Mozambique, Rwanda, Sierra Leone, United Republic of Tanzania, Tajikistan, Yemen, Zambia and Zimbabwe (FAO SOFI 2006).

There are indications that increased production of biofuels will further link prices of fossil fuels with biofuel feedstock. Prices of sugar and molasses already show high correlations with world oil prices. Increased production of biofuels adds another layer of uncertainty and risk to volatile price relationships by linking food and oil prices; inelastic demand (through biofuel consumption mandates) comprising an increasing share of a given crop's market also gives rise to greater price variability and market volatility. Increased price volatility may be more detrimental to food security than long-term price trends, to the extent that the poor are usually less able to adjust in the short term. Increased trade in biofuels has the potential to mitigate some of this price volatility. However, the expected price increases due to greater demand for biofuel crops may induce farmers to increase production and thereby mitigate some of these price effects in the longer term. Appropriate trade policies could potentially minimize tensions between biofuel and food production by allowing trade to flow internationally in response to fluctuations in domestic supply and demand, thus helping to stabilize prices.

Bioenergy and the four dimensions of food security

Availability of adequate food supplies refers to the capacity of an agro-ecological system to meet overall demand for food (including animal products, livelihoods and how producers respond to markets).

Food availability could be threatened by biofuel production to the extent that land, water, and other productive resources are diverted away from food production. The degree of potential competition between food, feed and fuel use of biomass will hinge on a variety of factors, including agricultural yields and the pace at which next-generation biofuel technologies develop. As second-generation technologies based on lignocellulosic feedstock become commercially viable, this may lessen the possible negative effects of land and resource competition on food availability. The market for biofuel feedstock offers a new and rapidly growing opportunity for agricultural producers and could contribute significantly to higher farm incomes. Modern bioenergy could make energy services available more widely and cheaply in remote rural areas, supporting productivity growth in agriculture or other sectors with positive implications for food availability and access to food.

Access to food refers to the ability of households to economically access food (or livelihoods), defined in terms of enough purchasing power or access to sufficient resources (entitlements). Bioenergy developments will have an impact on those populations vulnerable to food insecurity based on food access issues, to the extent that food prices rise faster than real incomes, reducing purchasing power and in turn, increasing food insecurity.

Global food commodity prices are expected to increase in the near to medium-term due to expanded biofuels production. Price increases have already occurred in major biofuel feedstock markets, for example, sugar, corn, rapeseed oil, palm oil, and soybean. In addition to raising feedstock prices, increased demand for energy crops might elevate the prices of basic foods, such as cereals, which comprise the major proportion of daily dietary intake of the poorest and least food secure. Thus, possible income gains to producers due to higher commodity prices may be offset by negative welfare effects on consumers, as their economic access to food is compromised. This appears to be the case for corn in 2006 and early 2007, as rising demand for biofuel production (ethanol) in the United States reduced exports, pressured prices, and in turn, threatened access to food for lower income net food purchasers in Mexico.

Stability refers to the time dimension of food security: Stability of food supplies refers to those situations in which populations are vulnerable to either temporarily or permanently losing access to resources, factor inputs, social capital or livelihoods due to extreme weather events, economic or market failure, civil conflict or environmental degradation, and increasingly, conflict over natural resources. Temporal distinctions between chronic and transitory food insecurity may be important to understand in the context of rapid bioenergy development. Chronic food insecurity is a long term or persistent inability to meet minimum food consumption requirements, lasting for more than six months of the year.

Transitory food insecurity is a short term or temporary inability to meet minimum food requirements, usually linked to the hungry (or lean) season, a more limited timeframe with some indication of capacity to recover from shocks.

Further growth in biofuels could exert additional pressures on stability of food supplies as price volatility from the petroleum sector is more directly and strongly transmitted to the agricultural sector, increasing the risk of more severe chronic and transitory food insecurity.

Utilization of food refers to peoples' ability to absorb nutrients: and is closely linked to health and nutrition factors, such as access to clean water, sanitation and medical services. The food utilization concept is also based on how food is used, such as nutrient loss during preparation, storage or processing, or cultural practices that negatively affect the consumption of enough nutritious food for certain family members, particularly, women and girls. If biofuel feedstock production competes for water supplies, it could make water less readily available for household use, threatening the health status and thus the food security status of affected individuals. On the other hand, if modern bioenergy replaces more polluting sources or expands the availability of energy services, it could make cooking both cheaper and cleaner, with positive implications for food utilization. Finally, determining the possible positive or negative effects on food security requires an understanding of the concept of vulnerability. Vulnerability in relation to food security is determined by the frequency and intensity of shocks affecting households and the capacity of these

households to withstand these shocks. Vulnerable households and communities may face acute food crises due to many factors (not just weather-related) and adopt extreme coping strategies to meet food needs. The long-term and cumulative effect of resorting to these types of coping strategies reduces more sustainable access to food as well as access to factor inputs necessary to restore livelihood security and/or own food production. This is clearly the case for many countries in sub-Saharan Africa.

Chronic food insecurity reduces household and community capacity to face human-induced and natural hazard shocks, particularly when faced with an acute food crisis. Repeated shocks, such as higher food prices, loss of income or source of livelihood, or loss of food crops due to extreme weather events, may force households to cope with chronic poverty and seasonal or cyclical food insecurity, depleting household assets and resulting in deteriorating food security.

Environmental issues related to bioenergy and implications for food security: The relationships between bioenergy and the environment, as related to food security, are complex and interdependent. Environmental and socio-economic benefits and trade-offs, particularly in terms of bioenergy and food security, must be analyzed and monitored across space and time. Energy (commodity) crops based on traditional agricultural output are already associated with land and soil degradation, water pollution and input and energy intensive production systems. Local environmental issues related to resource use and the potential for further degradation of the natural resource base may result in conflict over access and control over natural resources. At the global level, the environmental issues are related to climate change and the potential for bioenergy to mitigate greenhouse gas emissions. This will depend on feedstock used, technological conversion and the impact on the global energy balance. The most direct link between the environment, bioenergy and food security is the impact of climate change on vulnerable, food insecure households, mostly as it relates to the frequency and severity of extreme weather events. This is in particular true for sub-Saharan Africa.

5. Impacts on food security

Agriculture is not only a source of the commodity food but, equally importantly, also a source of income. In a world where trade is possible at reasonably low cost, the crucial issue for food security is not whether food is “available”, but whether the monetary and non-monetary resources at the disposal of the population are sufficient to allow everyone access to adequate quantities of food. The key factors that affect changes in access to food are real incomes and real prices for food. A greater role of bioenergy has an effect on both.

Price effects: Higher prices will reduce the purchasing power of consumers with adverse effects on their food security. But as discussed prices will neither increase indefinitely nor uniformly across all food products. In the long-run, neither food energy nor protein prices can rise faster than fuel energy prices in order for these feedstocks to remain competitive in the fuel energy market. This means that a global long-term food security problem due to increased bioenergy use would only be credible when and if real energy prices continue to rise. And even if they did, it would only reduce access to food and increase food insecurity if real food prices rose faster than real incomes.

In the short-run and during first-generation bioenergy use, prices for energy will rise faster than prices for protein. In a food insecurity situation where protein rich feedstocks are in short supply, the extra amounts of protein at lower prices would attenuate the adverse impacts from higher food energy prices, and may even make food rations more nutritious and thus improve the quality of food. As discussed, generally lower protein prices would be the outcome of a bioenergy scenario that would be based on the use of protein-rich oilseeds such as soybeans or rapeseed perhaps combines with the use of cereals such as maize or wheat as feedstocks for ethanol production. As also discussed, while these feedstocks indeed play an important role today, their low energy efficiency and their low carbon sequestration effects suggest that they will give way to more efficient converters of sunlight such as sugar cane or ligno-cellulosic feedstocks such as straw, miscanthus, poplar, or willow. In the long-run, it is also unlikely that the wedge between protein and energy prices will continue to increase.

Income effects: An increased use of bioenergy is likely to affect not only prices and price patterns but also levels and the distribution of incomes, particularly in developing countries. For farmers, bioenergy should

boost their overall revenues by raising both the prices they get for agricultural products as well as increased revenue from producing biomass for energy production.

For the interpretation of these price effects it is important to bear in mind that they reflect changes at the margin. Higher use may not simply have a proportionally higher price effect. The positive volume effect is due to the fact that bioenergy makes certain farm products such as straw or crop residues -- for which there is currently no market other than bioenergy - marketable products. A higher use of these products means that farmers may also face higher prices for some of their inputs and they may need to buy inputs like feedstuffs which were previously produced on the farm. In the long-run, they may also face higher wages if and where bioenergy boosts overall rural incomes. They may also face higher resource costs, notably higher land prices, as higher price for agriculture tend to capitalise on these scarce resources. Overall and notwithstanding the long-term adjustment processes in costs for land and labour, the positive revenue effect will exceed the costs and increase net farm incomes. Higher wages in rural areas and more employment effects should also increase overall rural incomes (trickle-down effect). The net effect on incomes in rural areas in general and in agricultural incomes in particular should thus be positive. And this also holds for access to food and food security in rural areas, and thus for 70 percent of all poor and undernourished, globally. The income effects of an increased use of bioenergy will also depend on the type of bioenergy with respect to factor demand. Where bioenergy is labour-intensive, factor incomes from cheap labour could help engender higher incomes for the poor.

Conversely, where bioenergy is capital-intensive and labour-saving, impacts on incomes and thus access to food could be negative. Particularly hard hit will be land-less rural households that are both net buyers of both food and energy, particularly if they fail to benefit from the macro-economic benefits that bioenergy can bring about (higher employment rates and higher wages). The exact effects of course require further empirical analysis and are influenced by governance of matters.

While many rural areas stand to benefit, urban households will face higher prices for food. Important here is to recall that food prices and energy prices rise in tandem and that the strength of the link between the two increases with rising energy prices. For net buyers of food and energy, this would be particularly negative. At the household level, a poor urban household with a high expenditure share on food and energy would be particularly hard-hit. What types of households stand to benefit or lose from the parallel increase of food and energy prices needs to be examined empirically.

Higher energy prices make a growing number of commodities competitive for the energy market, and thus lift their price with energy prices. In the long-run, higher levels of energy prices will also provide incentives for bioenergy investments and thus lead to a higher degree of market integration.

Another consequence will be a co-movement of energy and agricultural prices for more products and in a firmer manner for each product.

Importers of agriculture and energy, these countries are in a lose-lose situation as they face higher current account deficits from both product rubrics and the deficit is likely to accelerate with rising energy prices. As discussed below, within this lose-lose rubric, two cases are to be distinguished. First, countries which can pass on the higher import expenditures for food and energy to value-added export products; and second countries which import food and energy without being able to pass the extra costs onto their export sectors. In contrast, the positive extremes are countries that are traditional net exporters of both food and energy; these countries stand to benefit from price increases of both product categories and the increases in total current account surpluses are more than linear relative to the increases in oil price.

Indonesia or Malaysia fall into this win/win rubric. And finally there are countries that export either food or energy and they tend to win or lose depending on the relative size of the food or energy exports and imports

Food security is in particular critical for net importers of both food and energy. These are the countries that will experience the strongest negative effects on their current account as they face both higher expenditures for food *and* energy; and, as explained, the negative current account effect will accelerate as the link between food and energy prices get tighter as energy prices rise. These countries are likely to face a lose/lose situation not only for their current account but also as far as their food security situation is concerned.

However, as for individual households, the impacts of higher food and energy prices will not be uniform across all countries in the lose/lose category. While all countries will experience a similar negative effect on their import expenditures, there are considerable differences with respect to their ability to pass these

prices onto their exports and thus increase export revenues. Overall, the poorest of the poor may be particularly hard hit. Most LDCs are both net importers of food (43 of 52 in 2002/04), net importers of agricultural products in general (38 of 52 in 2002/04) and overall they have considerable and rapidly growing multibillion trade deficit for both food (US\$6 billion) and agriculture. As they are also the countries with the lowest level of GDP, the adverse effect from higher energy and agricultural imports relative to national incomes is likely to be particularly strong. How strong this effect is in practice will depend on the possibilities of individual countries to substitute for energy and agricultural imports or to pass higher import prices onto value-added exports.

Food availability

Food availability is the net effect of changes in production, net trade and stocks. In general, higher use of agricultural produce for non-food purposes should lower domestic food availability. The extent of lower food production would, however, depend on the type of feedstock used to produce bioenergy. Where bioenergy production is based on agricultural byproducts (straw, molasses, crop residues, cow dung, etc.) or an increased use of forestry products and by-products (wood chips, saw dust, etc.) that have been used for other industrial purposes (e.g. the paper and pulp industry) the impact on domestic food availability is likely to be small. This is the case for traditional bioenergy use in developing countries, which was based on by-products such as straw, crop residues or dung and could be the case for second-generation bioenergy which is likely to be based on ligno-cellulosic feedstocks such as wood or straw. The current, first-generation bioenergy feedstocks by contrast are largely based on food commodities which indeed compete either directly with food on the utilization side or at least indirectly on the production side for the resources needed (land, water, labour, capital) to produce food.

Higher domestic production of non-food products affects availability from trade, both directly and indirectly. Directly, as higher levels of non-food production (wood, etc.) are likely to lower the availability of food products for exports. Indirectly, as higher non-food exports could increase trade revenues and thus increase the purchasing power needed for food imports. This indirect effect would be particularly pronounced if and when the employment and income effect of a booming domestic bioenergy industry raises the purchasing power of people with low purchasing power and low food consumption levels. In this case, higher import availability would simply be a manifestation of enhanced access. As noted before, whether more food becomes available will therefore crucially depend on the distribution of the additional incomes generated by a burgeoning bioenergy industry.

Stability of food supplies

The stability element of food security relates to the risk of losing temporarily or permanently access to the resources needed to consume adequate food. While this risk has numerous components, important here is the risk that arises from possible swings in food prices that are pronounced enough to price poorer and food insecure segments of a population out of the food market. The basic question therefore is whether the rising demand for bioenergy makes agricultural prices more or less volatile. The impacts on price variability work through numerous channels and depend on many factors and a quantitative answer would have to be model-based.

A priori, a rising non-food demand should reduce the size of the food market and make this smaller market more susceptible to exogenous shocks. Fewer producers would make supply less elastic and thus less able to compensate for such a shock. What is more, demand for energy could be very inelastic in the short-run, particularly in rich industrial countries. This could mean that energy consumers in rich countries price food consumers in poorer countries out of the food market. However, there is also reason to assume that the expectations of a marked increase in price variability may not be justified and that prices may even be less variable in an agricultural market with higher bioenergy use. First, the overall energy market will not only create a floor price for agricultural produce but also a ceiling price. This ceiling price effect is due to the need for agricultural produce to stay below the energy price equivalent in order to remain competitive. This should put a cap on price hikes particularly in the long-run. There are also reasons to assume that this very mechanism will even be effective in the short(er)-run, particularly if prices increase in a pronounced way. The main reason for the limits on short-run price peaks is that feedstocks account for a large share of total costs and this share of course rises further if feedstock costs increase. In large ethanol production plants, for instance, feedstock costs can account for about 70-80% of total costs. This means that the short and long-term production criterion for profitability in such plants will be close to each other and that they will cease

converting food into bioenergy altogether when feedstock prices become too expensive. In other words, when variable costs cannot be covered, plants will stop producing in the short run and thus help stabilise prices.

Given the high market integration of this market and its significant size both in domestic energy and international sugar markets, the non-food use of sugar works like a giant buffer stock for the sugar market that releases sugar on the market when it becomes too expensive for ethanol production and sucks it up when sugar is too cheap and it is more profitable to produce bioenergy out of the same feedstock. It can already be shown that not only the price levels of sugar but also the variability of the sugar prices follows closely the variability of energy prices; with the growing integration of the sugar-ethanol market, magnitude and frequency of sugar price variations closely trace those in crude oil.

The high degree of integration in the sugar market is however not (yet) characteristic of other agricultural feedstock markets. In most bioenergy markets substitutability is still low and rising utilization of agricultural feedstocks for bioenergy eats into the volumes of the corresponding food markets. This is particularly the case for many perennial crops (miscanthus, poplar, willow, etc.) where the limited or completely missing substitutability in conjunction with a multi-year area allocation to non-food production makes it more difficult to shift from non-food use to food use and vice versa. A massive shift towards such feedstocks may make overall food markets more susceptible to price shocks.

The discussion of the impacts of an increased bioenergy use shows that higher agricultural land energy prices can provide both a threat to but also an important opportunity for improving food security. At the country level, the short-term *static* effects of the likely price changes for food and energy will crucially depend on the net trade position for these products and the ability of a country to pass on higher import prices to higher export values for derived products.

Policies can play an important role in mitigating the adverse effects on net buyers of food and energy and ensure that net sellers of both are able to fully harness the benefits. If and where the right policies are in place, the use and production of bioenergy affords rural areas the chance of a renaissance. It could help attract resources back into the countryside, mitigate urbanisation pressures and initiate a new rural dawn.

While bioenergy has the potential to arrest the long-term downward trend in real prices for food and agriculture, the effect may be limited in time and size and even a longer interruption in falling real prices may not mean a complete and permanent departure from the century-long downward trend. Episodes of rising real prices are not new and the long-term price decline over the last century was characterised by three periods of rising real prices (1900-18, 1933-48, 1973-80, 2000- 2007). These periods lasted more than a decade and they were typically followed by pronounced bust cycles. High-price periods have led farmers to expand and intensify production, invest in land and technology and assume debt to an extent that has later proven unsustainable. What is more, much of the increased price was typically capitalized in the price of land rather than resulting in the longer-term profitability of farm operations. Higher values of collaterals, high short-term profitability followed by pronounced bust cycles led to large amounts of non-performing loans in agriculture and periods of widespread financial distress in farming. The US "farm crisis" of the 1980s is the most recent example (Gardner, 2003).

The current bioenergy-triggered boom could also be followed by a marked bust cycle. It could be ushered when the second generation biotech feedstocks enters the market on a large scale. Second-generation technologies could make many of the first generation feedstocks (i.e. the traditional agricultural and food commodities) unprofitable and result in a demand and price shift from food commodities to forests commodities. This shift could make not only first-generation feedstock production unprofitable, but the entire production chain as well because second-generation processing technologies will be entirely different. For food prices, this should result in less demand and possibly a return to falling real prices.

New support and protection policies in developed and developing countries for bioenergy, combined with new policy initiatives (CDM, JI, GEF, etc.) at the international level and a growing engagement by International Financial Institutions could add to possible overinvestments in bioenergy production. The simultaneous commitment to investing in the same sector could result in a global "*fallacy of composition*" problem. As more efficient first-generation plants come on stream and as second-generation technologies enter the bioenergy markets, a lot of investments in first-generation bioenergy could turn sour or remain

only profitable if real prices for fossil energy remain high and rising. The first signs of such problems are already visible in the low profitability of maize-based biogas production in Germany and of maize ethanol plants in the US given currently rising maize prices.

However, *many rural households stand to benefit* both through higher prices for their produce and higher volumes of marketable production. As 70 percent of the poor live in rural areas, the overall net effect on food security could be positive. While rural households stand to benefit as sellers of food and energy, *urban households stand to suffer* from higher expenditures for both.

6. The key position of agriculture

The potential biomass resource base is diverse. A no-regret potential in the form of organic residues and wastes, as well as opportunities for the use of e.g. degraded lands seems to provide a foundation. But the larger part of the opportunities lay in agriculture (including livestock production). The question is therefore that what extent such changes in agricultural management, although in theory possible, actually be implemented in reality?

In spite of a threefold increase in world population since the Second World War, the fastest increase ever in human history, available calories per capita have grown by nearly 25%. This amazing achievement is the combined result of academic research, government policy and private investment. It shows that agricultural research has been one of the most rewarding economic sectors. We can draw an important lesson from this: human capacity to innovate is great and allows us to be confident that collectively we are capable of innovation and rapid change. Food demand has always been driven by population increase, income growth and changing diets. Aggregate agricultural output, on the other hand, is a function of available arable land, agricultural productivity, input prices and commodity prices. World population is still expected to grow, probably stabilising at around or slightly over 9 billion in 2050. Future food production is, by default, expected to increase by about 1% annually as a result of increased productivity (assuming arable land remains roughly the same)^[vi]. The most important growth sector within agriculture is the animal production sector with the demand for animal feed, particularly in Asia, driving world market prices. About 40 % of the world's cereal crops are used to feed livestock. Agricultural production is likely to double by 2030 to meet rising demands and shifting dietary patterns. While the agricultural techniques to achieve the required growth already exist, their application is an important challenge and should by no means be taken for granted everywhere, especially not in Africa and in ecologically disadvantaged regions.

For the future, hardly any new high quality land is available and no new land should be taken into production because this will be at the expense of forest and valuable nature - so all production must come from cultivated land, including degraded and fallow land, currently in use³. The only real option for satisfying growing demand is therefore through a process of sustainable intensification, with due regard to the lessons learnt from irrational and poor use of agrochemicals and water in the past. Sustainable intensification is defined as an increase in the efficiency of the use of land, water and chemicals (fertilizers and pesticides), using modern husbandry techniques to tend new genotypes of crops and animals, while avoiding environmental degradation. This boils down to what has been called a second or doubly Green Revolution, boosting land, water and labour productivity and enabling greater diversification of diets and income generation in rural areas. There is an entire suite of new techniques and production systems that have proven their values in experimental and operational situations in countries as far apart as Brazil and Kenya, the Netherlands and China. They centre around principles like maximum ground cover to improve water infiltration, prevent erosion and destruction of soil organic matter; the judicious timing of the

[vi] The earth's land surface is 13bn/ha . Arable land currently in use is estimated at 1,6 bn ha. Total arable land suitable for rainfed crop cultivation is estimated at 4 bn. Ha. The area of pasture land is about twice the area of crop land. Source: FAO 2007. According to the IEA about 14 million hectares of arable land are currently used for the production of modern bio-fuels IEA, World Energy Outlook 2006, p.385.

3 Bio-saline agriculture for instance, may bring into play large areas of saline waste land.

application of chemicals such as fertilizers as well as animal growth stimulators to avoid excessive dosages and emissions to the surrounding ecosystems; the reduction of the use of pesticides through widespread utilisation of genetic resistance and biological control methods; clever combinations and diversity of perennial and annual crops, including agro-forestry; the optimal use of mechanisation such as no-till farming, precision farming; the selective use of biotechnology (insect resistant strains of animals and crops with improved root systems); judicious water use through drip and deficit irrigation; virtually closed horticultural systems and, last but not least intensive, low emission and high hygiene livestock production systems.

Although the proportion of people in the agricultural sector will decrease overall, many countries, especially in Africa, will remain heavily dependent on agriculture. Seventy percent of the world's poor live in rural areas and 50 % of the world's population still depends on conventional biomass for basic energy services. For them agriculture will continue to be a main driving force for development, and in these areas a modernisation of agriculture through a new Green Revolution is badly needed. Whatever forms bio-energy takes, they must be part of this wider trend of modernization through increased efficiencies in the use of land, water, labour and other inputs.

Biomass for food or fuel?

Whether and how bio-energy impacts on food security and sustainability depends on many factors: stating that food and fuel are on forehand conflicting demands poses a misleading dilemma because an immediate and massive displacement of food crops by energy crops seems very unlikely. Nevertheless, public concern about the displacement of food crops, especially in poor countries, is rising. Bio-fuels currently take less than 20 Million hectares worldwide, compared this to the 5000 million hectares (sum of arable and pasture lands) that are used world wide for food and feed. It is unlikely that the net impact on food prices directly related to bio-fuel production can be large, so there are other factors explaining concerns. Speculation and artificial price mechanisms may create short and medium term market distortions which may have an upward effect on land and feed/food prices, thereby fuelling concerns about future food supplies as in the case of the 2007 "tortilla war" in Mexico. The growing demand for food and feed as such, liberalised trade and decreasing stocks (which makes prices much more volatile than in the past) contribute to the current atmosphere. The reaction in Mexico is a case in point, as the country paid the price for the NAFTA treaty which made it much more dependent on (subsidized) imports from the US and led to a reduction of maize production nationally. The price hike caused by the shortages in supply also leads to rapid responses in increasing maize production in Mexico again and makes farming (and investments in better and more investment in more efficient production) more viable. The Tortilla crisis has been a short-lived matter.

Nevertheless, we ought to be aware of a potential conflict where forms of currently inefficient and subsidized bio-fuel production continues to compete on land also in use for food and feed. Governments aiming at a significant role of bio-fuels in the near future, must formulate realistic targets based on correct production levels and conversion rates. Thus far, policy choices in this area are evidently not driven by economic efficiency but by strategic and geopolitical considerations such as increased energy self reliance. The US and EU have now put in place import quota and or import levies which impede free international trade of bio-fuels. Only under such conditions the risk of price induced competition between food and fuel augments.

In developing countries substitution of food by fuel crops is unlikely because biomass as such is not easily traded across large distances, i.e. it is unlikely that the developing world will be used in a massive way for the production of clean energy alternatives of the developed countries or China and India. Moreover, the demand for food and feed, especially is rising, and will boost farmers' incomes and willingness to invest in food crops. Nevertheless, global trade, and the related international logistics, in bio-fuels (liquid and solid, such as pellets, as opposed to feed stocks) is growing rapidly and efficiently. This should be seen in a positive light for potential exporting countries. These are countries, especially in Africa, where local energy needs are still low and where there is little other export potential. The role of bio-fuels may be compared here with the role of a cash crop like cotton or coffee: it allows a greater cash flow and hence greater investment in the rural sector. However, while in rich countries competition can easily be avoided, if government policy promotes efficient conversion routes and use biomass resources that do not infringe on food production, poor countries tend to have weak governments and hence the risk of exploitation of poor

farmers should not be underestimated. This would require also the judicious use of ODA moneys for rural areas.

The food or fuel dilemma is probably more adequately renamed feed or fuel, since the main energy crops – maize, soy bean – are also feed crops. Thus bio-fuels present a direct competition to the expanding livestock sector, which reflects the shift in dietary patterns in newly developing countries. There are also synergies here since growing feed demand can be partly offset by by-products of bio-fuel such as meal. Whether fuel crops will replace feed crops is largely a matter of price and consumer preferences. Thus far, rising incomes lead always to higher animal protein consumption. Feed and fuel may well be complementary and allow farmers greater flexibility to switch livestock or feed production for bio-energy commodities. Grasslands represent large land surfaces that are often used inefficiently by free grazing cattle. Managed grassland could be a major and very attractive biomass supplies.

In specific areas in developing countries theoretically a wood or fuel dilemma might arise since the second generation conversion of lignocelluloses biomass from wood or stalks seems to present great promises.

Wood does not compete directly with human or animal food, but that is not to say that this biomass has no use: in developing countries (and some northern hemisphere countries) it serves in a major way as and construction material and firewood. However, this latter use should be ultimately discouraged and replaced by more efficient uses. Stalks and stubble of course may also have an important local use as ground cover, soil improvement and feed and can make a true difference in poor areas. Typically, after an annual crop the stubble yield is 6-8 t/ha which is significant, and could play a part soil carbon fixation.

How much land is needed?

How much land is available for energy farming depends on how much is needed for the production of food and feed. This in turn depends on agricultural productivity and changing dietary patterns^[xxii]. According to the FAO there is little evidence to suggest that global land scarcities lie ahead. Between the early 1960s and the late 1990s, world cropland grew by only 11 percent, while world population almost doubled. As a result, cropland needed per person fell by 40 percent, from 0.43 ha to only 0.26 ha. whereas world population has almost doubled. Yet, over this same period, nutrition levels improved considerably and the real price of food declined. This trend is explained by a spectacular increase in land productivity which reduced land use per unit of output by 56% over the same period. Although an estimated 4 bn ha are considered suitable for rainfed crop production, only some 1,6 bn is currently in use. This is not to say that regional shortages cannot occur as a result of energy crop cultivation, particularly as these surpluses are not evenly distributed globally, nor that in some regions competing claims on water resources and soil nutrients need not be reconciled.. It merely indicates that on a global scale concerns about food security or loss of nature and biodiversity are not warranted.

The actual claim on arable land resources implied by the large scale cultivation of energy crops depends to a large extent on the crop choice and the efficiency of the entire energy conversion route from “crop to drop”. This is illustrated by the figures in table 1. It is important to stress that when lignocellulose is the feedstock of choice production is not constrained to arable land, but amounts to the sum of residues and production from degraded/marginal lands not used for current food production. Ultimately, this will be the preferred option in most cases.

Table 1; indicative ranges for biomass yield and subsequent fuel production per hectare per year for different cropping systems in different settings. Starch and sugar crops require conversion via fermentation to ethanol and oil crops to biodiesel via esterification (commercial technology at present). The woody and grass crops require either hydrolysis technology followed by ethanol or gasification to syngas to produce synthetic fuel (both not yet commercial conversion routes).

Crop	Biomass yield (odt/ha* yr)	Energy yield in fuel (GJ/ha*yr)
Wheat	4 - 5	~ 50
Corn	5 - 6	~ 60

^[xxii] The US national Agricultural Biotechnology Council estimates that with 10 bn people required arable land for food would be 2.6-1.2 bn ha (low /high yield) whereas available arable land will shrink to 1.1-2.1 bn ha., NABC report 12 (2000)

Sugar Beet	9 – 10	~ 110
Soy Bean	1 – 2	~ 20
Sugar Cane	5 – 20	~ 180
Palm Oil	10-15	~ 160
Jathropha	5-6	~ 60
SRC temperate climate	10 – 15	100 - 180
SRC tropical climate	15 - 30	170 - 350
Energy grasses good conditions	10 - 20	170 – 230
Perennials marginal/degraded lands	3 - 10	30 – 120

Production of biomass not only depends on available land but also on limiting factors, in particular water and nutrients. Nutrient deficiencies should not be overestimated as they can be remedied by efficient fertiliser use, which it self should also be produced efficiently. Nitrogen is ample available and although its production is energy intensive it can be produced using renewable energy. Phosphate is hardly an issue for perennial crops, because their Phosphate use is far lower than annual crops and is mainly retained in the ecosystem through the root system and litter fall; the recycling of ashes after the conversion of the crop into energy limits phosphate needs (as is done in e.g. Austria and Sweden), but phosphate must often be supplied in young plantations to jump start the seedlings.

Water scarcities can be a serious matter, and is highly political, mostly locally and regionally specific and mainly a matter of price. The lack of national water and water pricing policies and legislation to promote efficiencies are a great barrier in semi-arid and arid areas, to agriculture in general and hence to water use in biomass production. Adequate agricultural management techniques exist in many cases and research is underway to promote higher efficiencies through specific temporal application (“water the plant root, not the soil, and water the plant when the fruit is developing, not before”) using e.g. drip irrigation and so-called deficit irrigation that reduce water use even more. Dramatic improvements in recycling run off and percolated water can be achieved, so that the only water consumption is in evapotranspiration. In some case biomass crops can contribute to improved water management and retention functions, especially in reforestation schemes.

If the resource base for bio-fuels is expanded to cellulosic feedstocks such as grasses and fast growing trees such as willow or eucalyptus growing the whole picture changes dramatically. Not only is the net energy yield per hectare considerably higher (see table 1), but these crops also open up a much larger land-base for production compared to annual crops. Conversion of lignocellulosic biomass requires the availability of commercial conversion processes for such feedstocks and the market and supply infrastructure needed for the 2nd generation bio-fuel production capacity.

New species as feed stock

Apart from the matter of on what land bio-energy crops should be produced and hence apart from the direct competition with crops for food and feed, a new area of research opens up with the use of new species and varieties. In terms of plants, the search is on for species that cannot be consumed by humans or animals. Experience with species such as Jatropha that are exclusively grown for their energy content are promising. Many of these grow under harsh conditions on soils that are unsuitable for most food or feed crops. The challenge will be to reduce water use to a minimum so that they fit marginal conditions. Today, many of these so-called wild species are often very low in yield (a maximum of 1,5 ton oil /ha /yr on poor soils) and major breeding efforts are still needed to increase their productivity. In general, the same applies as for any market crop such as cotton: if these new crops are grown on previously cleared land, especially in a rotation with food crops, they could provide useful cash revenue to farmers and would complement food production rather than displace it. The use of species adapted to marginal conditions in combination with improved husbandry methods in grazing systems of small ruminants, now often one of the lowest yielding agricultural systems in the world, would allow to free up this land to grow crops like Jatropha spp or harvest of grasses. In fact, innovations in protein production (e.g. via algae, new fish farm concepts, even bio-refining certain crops directly, single cell proteins) may lead to substantial efficiency increases in

protein production and thus reduced land demand compared to the base projections. Land shortage, in other words, is unlikely to be the major long term factor in the biomass for food or fuel debate.

7. State-of-the-art insights in biomass potentials; a quantified and integrated view.

A recent comprehensive assessment has been made of global biomass potential estimates, focusing on the various factors affecting these potentials, such as food supplies, water use, biodiversity, energy demands and agro-economics. In addition, a number of studies analysing GHG balances of bioenergy are discussed. After an extensive inventory of recent studies in the different areas (food, water, biodiversity, agro-economics and energy demand); this study integrates the complicated linkages between the various factors, quantifying the consequences of the linkages and knowledge found in the inventory within the limits of the presently available models. The results are translated into an overview of the uncertainties in biomass resource potential estimates and summarises the available knowledge and knowledge gaps. This analysis leads to policy relevant recommendations for sustainable biomass use in the future including R&D needs.

The assessment focused on the relation between estimated biomass potentials and the availability and demand of water, the production and demand of food, the demand for energy and the influence on biodiversity and economic mechanisms. None of eight recent potential studies assessed covers the whole range of issues, but they all have their strong and weak points, as shown in table 2. The scope of the studies, in terms of biomass resources included, varies as well as scenario and methodological assumptions. As a consequence, global biomass supply potentials vary widely. The highest biomass potential of 1500 EJ for 2050, which can be considered the technical upper limit determined by Smeets et al. (2007) is based upon an intensive, very high technologically developed agriculture. On the contrary, the zero biomass potential for 2050 calculated by Wolf et al. (2003) is caused by assuming a pessimistic scenario: high population growth, high food demands and extensive agricultural production systems. The study of Hoogwijk et al. (2005) refers to production of energy crops on abandoned, marginal and rest land assuming global and regional trends as described in the IPCC SRES scenarios, with increasing agricultural efficiency over time, leading to a potential of about 650 EJ in the best scenario.

Table 2: Overview and evaluation of selected biomass potential studies

Study	Subject	Biomass potential	Evaluation
Fischer et al., 2005	Assessment of eco-physiological biomass yields	CEE, North and Central Asia; EC (poplar, willow, miscanthus); TP	<i>Strong:</i> detailed differentiation of land suitability for biomass production of specific crops on a grid cell level (0.5 degree) <i>Weak:</i> not considering interlinkages with food, energy, economy biodiversity and water demands
Hoogwijk et al., 2005	Integrated assessment based on SRES scenarios	Global, EC (short rotation crops); TP	<i>Strong:</i> integrated assessment considering food, energy material demands including a scenario analyses based; analyses of different categories of land (e.g. marginal, abandoned) <i>Weak:</i> crop yields not modelled detailed for different species and management systems
Hoogwijk et al., 2004	Cost-supply curves of biomass based on integrated assessment	Global; EC (short rotation crops; TP, EP (as cost-supply curve)	<i>Strong:</i> establishes a global cost-supply curve for biomass based on integrated assessment <i>Weak:</i> linkage land/ energy prices not regarded
Obersteiner et al., 2006	Biomass supply from afforestation/ reforestation activities	Global; F (incl. short rotation); EP	<i>Strong:</i> modelling of economic potential by comparing net present value of agriculture and forestry on grid-cell level <i>Weak:</i> yields of forestry production not dependent on different technology levels

Perlack et al., 2005	Biomass supply study based on outlook studies from agriculture and forestry	USA; EC, F, FR, AR, SR, TR; TP	<i>Strong:</i> detailed inclusion of possible advances in agricultural production systems (incl. genetic manipulation) <i>Weak:</i> no integrated assessment, e.g. demands for food and materials not modeled
Rokityanski et al., 2007	Analysis of land use change mitigation options; methods similar to Obersteiner et al., 2006.	Global; F (incl. short rotation); EP	<i>Strong:</i> policy analysis of stimulating land use options including carbon prices <i>Weak:</i> agricultural land not included
Smeets et al., 2007	Bottom-up assessment of bio-energy potentials	Global; EC, F, AR, FR, SR, TR; TP	<i>Strong:</i> detailed bottom-up information on agricultural production systems incl. animal production <i>Weak:</i> yield data for crops only regionally modelled
Wolf et al., 2003	Bottom-up assessment of bio-energy potentials mainly analyzing food supplies	Global; EC; TP	<i>Strong:</i> various scenarios on production systems and demand showing a large range of potentials <i>Weak:</i> yields of energy crops not specified for different species and land types

Biomass: EC – energy crops, F: forestry production, FR: primary forest residues, AR: primary agricultural residues, SR: secondary residues, TR: tertiary residues. Potentials: TP – technical potential, EP – economic potential

These recent biomass potential studies give detailed and well-founded insights into future biomass potentials, but none of the studies does include all critical aspects combined. Important issues that deserve further attention are:

- The competition for water with other economic sectors,
- Human diets and alternative protein chains have been included to a limited extent only
- The impacts of different animal production systems need to be studied in more detail
- The demand for wood products and other bio-materials has been simplified and has not been modelled based on economic scenario analysis.
- The impact of large-scale biomass production on the prices and subsequently on the demands of land and food has not been sufficiently studied.
- The impact of specific biodiversity objectives on biomass potentials has not been investigated in detail.

The *biodiversity* effects of growing bio-energy crops are usually not taken into account in the different global potential studies. Biodiversity is typically treated by assuming that present nature conservation areas are excluded from biomass production. As such, the estimated biomass potentials take biodiversity into account, but at a limited base level only. Many other diverse research papers do report on actual biodiversity effects of bio-energy production (or comparable crops), but show different and sometimes opposite results. This is caused by using different time horizons (short or long term), different scales of observation (local, regional or global), and the different biodiversity definitions used. Often, the used biodiversity concept is not explicitly defined. It can vary from “naturalness” (e.g. the extent of natural habitats), to “agro-biodiversity” (e.g. number of crop species).

At the local scale, the noted effects mostly depend on the former land-use and the type of bio-energy crops that are grown. When natural areas are used, (natural) biodiversity is obviously lost through land conversion. First generation European agricultural crops do worse at the local level than mixed cropping systems, second generation perennials and woody crops.

With regard to *water* the studies showed large differences: in some regions abundant water availability provides ample opportunities for energy crop production, while water scarcity in other regions is seriously restricting any opportunity for energy crops. Comparing the different analyses shows that problems are

analysed at a higher scale than the solutions formulated. The large variability in regional climate and hydrology asks for a detailed and local analysis of the biophysical possibilities for crop production. To determine water availability for energy crop production a basin scale seems most appropriate in order to assure that the interaction between upstream and downstream water availability and use is taken care of. The local situation should be analysed to assess the scope for energy production. However, to date, studies at this resolution have only been done incidentally, and global figures give a misleading picture. From the assessment it also became clear that generally, water use efficiency of agriculture can be improved considerably using more optimal management techniques. Such more controlled management systems may also prove more robust to the impacts of climate change and combined with more resilient perennial cropping systems, may serve as an adaptation strategy as well. Such links between agricultural and land management and response to changing climate conditions are so far poorly studied.

Climate change is likely to change rainfall patterns while water transpiration and evaporation will be enhanced by increasing temperatures. The net effect of this is not easy to predict, large variations can be expected among different regions of the world. Especially semi-arid and arid areas are expected to be confronted with reduced water availability and problems in many river basins may be expected to increase. Generally, negative effects of climate change will outweigh the benefits for freshwater systems, thereby adversely influencing water availability in many regions and hence irrigation potentials.

The *agro-economic studies* that have been carried out often deal with agricultural land and do not take into account forestry land. They also do not deal with second generation biofuels. The studies carried out illustrate the necessity of including competition and interactions between agricultural markets. The production of biofuels affects prices of feed and food. Those effects have to be taken into account in order to present a realistic picture of available biomass for biofuel. These effects are also relevant to assess the social sustainability of bio-energy, especially the effects on regional incomes and food security. The key-parameters for the driving forces behind agro-production vary and are *dynamic*.

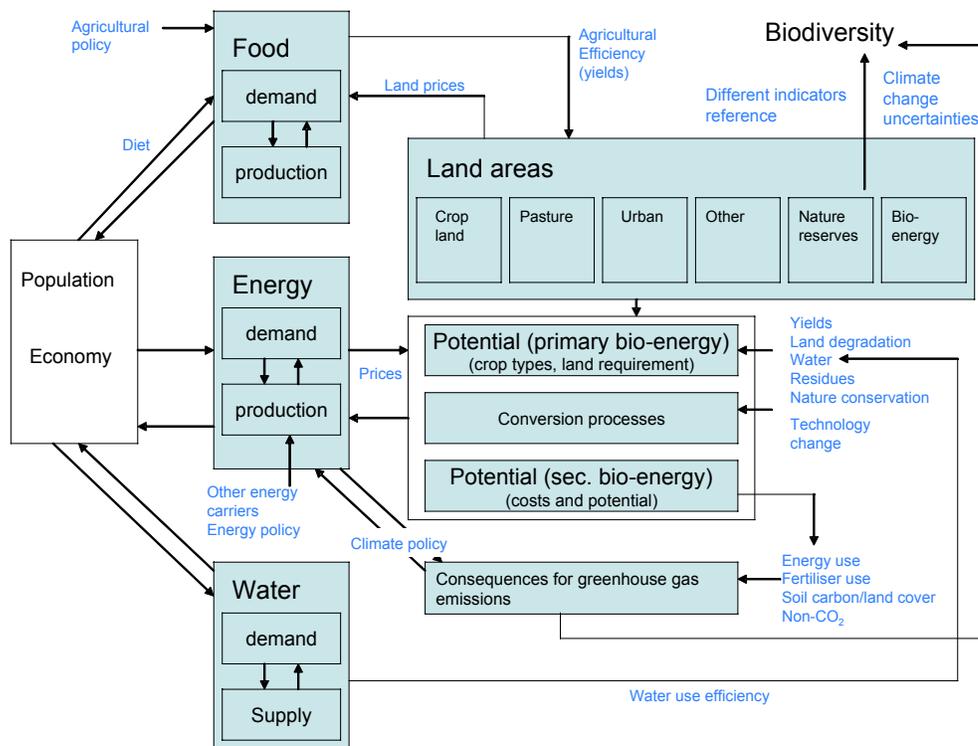


Figure 1: Overview of key relationships relevant to assess potential bio-energy supply.

Insights into the impacts of more integrated considerations are given by performing some sensitivity analysis using existing models. The aim of these analyses is not to provide final quantitative answers, but instead to assess the possible impacts of some key uncertainties. Some key issues:

1. The role of bio-energy use in energy models, in particular to identify which factors limit the penetration of bio-energy. The result of two MARKAL runs showed that biomass is mostly limited by its marginal cost, not by its supply potential. TIMER runs with different taxation levels showed that biomass stabilizes at 130 EJ at taxation levels of above US\$100/tonne carbon. Biomass feedstock for the power sector should have costs below 3 US\$/GJ to be fully competitive at carbon prices below US\$100/tonne C.
2. The sensitivity of bio-energy potential estimates to issues such as uncertain development of agriculture technologies, land use, water scarcity, land degradation and nature reserves. A typical example for water scarcity: overlaying the bio-energy map with the water scarcity maps of the WaterGap model suggests that about 15% of the total potential for bio-energy is in severe water scarce areas (and might therefore be excluded) and another 5% is in areas with modest water scarcity.
3. Key uncertainties in assessing biodiversity losses as a result of land conversion for bio-energy. In the baseline OECD scenario biodiversity (MSA) declines by 11% between 2000 and 2050. For an ambitious 450-ppm option for climate change mitigation, large scale bio-energy production is implemented with mainly woody biofuels. For this, 1.8 million km² of abandoned agricultural land is used, and a further 3 million km² of extensively used grasslands (considered having a semi-natural character) are converted. Compared to the baseline, the total biodiversity decline in the option is 1% less (relative difference of 10%).

The integration analysis provided answers to a key questions, but also showed knowledge gaps and uncertainties. The key uncertainties identified in this study are summarized in table 3 below (column 1). They are evaluated according to their importance (column 2) and the impact on biomass potentials as estimated in the literature reviewed is presented (column 3). In addition also the results of the integration phase are presented (column 4). Percentages of supply refer to the OECD baseline scenario in IMAGE that estimates biomass potentials of about 200 EJ/yr. It should be noted that the results of the integration analysis provide an order of magnitude but are not based on an integrated modelling analysis.

Table 3: Overview of uncertainties and their impact on biomass resource potentials

Issue/effect	Importance	Impact on biomass potentials compared to	
		supply as estimated in recent studies	OECD baseline scenario in IMAGE
<i>Supply potential of biomass</i>			
Improvement agricultural management	***	≠↓	≠ 40-65%
Choice of crops	***	↓	↓ 5-60%
Food demands and human diet	***	≠↓	n/a
Use of degraded land	***	≠↓	≠ ca. 30-45%
Competition for water	***	↓	↓ 15-25%
Use of agricultural/forestry by-products	**	≠↓	n/a
Proceted area expansion	**	↓	↓10-25%
Water use efficiency	**	≠	n/a
Climate change	**	≠↓	n/a
Alternative protein chains	**	≠	n/a
Demand for biomaterials	*	≠↓	n/a
GHG balances of biomass chains	*	≠↓	n/a
<i>Demand potential of biomass</i>			
		demand as estimated in recent studies	biomass supply as estimated in TIMER
Bio-energy demand versus supply	**	≠↓	↓ 80-85%

Cost of biomass supply	**	≠↓	n/a
Learning in energy conversion	**	≠↓	n/a
Market mechanism food-feed-fuel	**	≠↓	n/a

Importance of the issues on the range of estimated biomass potentials: ***- large, ** - medium, * – small
 Impact on biomass potentials: potentials as estimated in recent studies would: ≠ - increase, ↓ - decrease, ≠↓ increase or decrease – if this aspect would be taken into account.
 N/a: no quantitative analysis has been carried out.

In principle, biomass potentials are likely to be sufficient to allow biomass to play a significant role in the global energy supply system. Current understanding of the potential contribution of biomass to the future world energy supply is that the total technical biomass supplies could range from about 100 EJ using only residues up to an ultimate technical potential of 1500 EJ/yr potential per year. The medium range of estimates is between 300 and 800 EJ/yr (first column of figure 2 below). This assessment has provided several sensitivity analysis of available results to date, especially with respect to water availability, soil quality and protected areas. These are significant and led to corrections to earlier estimates of the resource potentials. Thus, the present study gave more insight in the various factors influencing biomass potentials tuning down the range of about 200 to 500 EJ/yr (second column of figure 2)

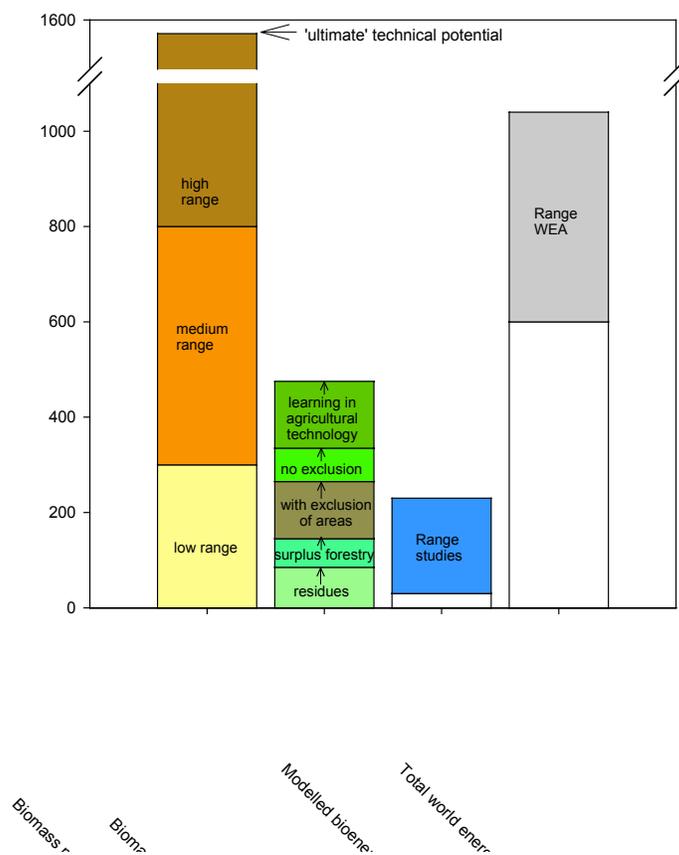


Figure 2: Comparison of biomass supply potentials in the review studies and in this study with the modelled demand for biomass and the total world energy demand, all for 2050.

The biomass potential, taken into account the various uncertainties as analysed in this study, consists of three main categories of biomass:

1. Residues from forestry and agriculture and organic waste, which in total represent between 40 - 170 EJ/yr, with a mean estimate of around 100 EJ/yr. This part of the potential biomass supplies is

relatively certain, although competing applications may push the net availability for energy applications to the lower end of the range. The latter needs to be better understood, e.g. by means of improved models including economics of such applications.

2. Surplus forestry, i.e. apart from forestry residues an additional amount about 60-100 EJ/yr of surplus forest growth is likely to be available.
3. Biomass produced via cropping systems:
 - a. A lower estimate for energy crop production *on possible surplus good quality agricultural and pasture lands*, including far reaching corrections for water scarcity, land degradation and new land claims for nature reserves represents an estimated 120 EJ/yr (“*with exclusion of areas*” in fig ES.2)
 - b. The potential contribution of *water scarce, marginal and degraded lands* for energy crop production, could amount up to an additional 70 EJ/yr. This would comprise a large area where water scarcity provides limitations and soil degradation is more severe and excludes current nature protection areas from biomass production (“*no exclusion*” in fig ES.2).
 - c. *Learning in agricultural technology* would add some 140 EJ/yr to the above mentioned potentials of energy cropping

The three categories added together lead to a biomass supply potential of up to about 500 EJ.

Energy demand models calculating the amount of biomass used if energy demands are supplied cost-efficiently at different carbon tax regimes, estimate that in 2050 about 50-250 EJ/yr of biomass are used. At the same time, scenario analyses predict a global primary energy use of about 600 – 1040 EJ/yr in 2050 (the two right columns of figure 2). Keep in mind that food demand of around 9 billion people in 2050 are basically met in those scenario’s (be it with regional differences still in calorie intake between different world regions, although these are expected to be considerably smaller than today).

This study has confirmed that annual food crops may not be suited as a prime feedstock for bio-energy, both in size of potentials and in terms of meeting a wide array of sustainability criteria, even though annual crops can be a good alternative under certain circumstances. Perennial cropping systems, however, offer very different perspectives. These cannot only be grown on (surplus) agricultural and pasture lands, but also on more marginal and degraded lands, be it with lower productivity. At this stage there is still limited (commercial) experience with such systems for energy production, especially considering the more marginal and degraded lands and much more development, demonstration (supported by research) is needed to develop feasible and sustainable systems suited for very different settings around the globe. This is a prime priority for agricultural policy.

As summarized, the size of the biomass resource potentials and subsequent degree of utilisation depend on numerous factors. Part of those factors are (largely) beyond policy control. Examples are population growth and food demand. Factors that can be more strongly influenced by policy are development and commercialization of key technologies (e.g. conversion technology for producing fuels from lignocellulosic biomass and perennial cropping systems), e.g. by means of targeted RD&D strategies. Other areas are:

- Sustainability criteria, as currently defined by various governments and market parties..
- Regimes for trade of biomass and biofuels and adoption of sustainability criteria (typically to be addressed in the international arena, for example via the WTO).
- Infrastructure; investments in infrastructure (agriculture, transport and conversion) is still an important factor in further deployment of bio-energy.
- Modernization of agriculture; in particular in Europe, the Common Agricultural Policy and related subsidy instruments allow for targeted developments of both conventional agriculture and second generation bio-energy production. Such sustainable developments are however crucial for many developing countries and are a matter for national governments, international collaboration and various UN bodies (such as FAO).
- Nature conservation; policies and targets for biodiversity protection do determine to what extent nature reserves are protected and expanded and set standards for management of other lands.
- Regeneration of degraded lands (and required preconditions), is generally not attractive for market parties and requires government policies to be realized.

Current insights provide clear leads for further steps for doing so. In the criteria framework as defined currently by several governments, in roundtables and by NGO's, it is highlighted that a number of important criteria require further research and design of indicators and verification procedures. This is in particular the case for to the so-called 'macro-themes' (land-use change, biodiversity, macro-economic impacts) and some of the more complex environmental issues (such as water use and soil quality).

It is confirmed that in principle technical and economic biomass resource potentials could be very large on a global scale (up to one third of global energy demand following more average projections for energy demand as well as biomass resource potentials). However, only a smaller part of the larger potential estimates will be almost certainly available (namely the biomass residues and organic wastes). The larger part of the potential has to be developed via cultivation and has to meet a wide variety of sustainability criteria to avoid conflicts with respect to water use, land-use competition, protected areas, biodiversity, soil quality and socio-economic issues. Based on the findings in this assessment, for large parts of the resource potentials the indications are that such conflicts can indeed be avoided or may in parts even result in co-benefits. The latter could be true for using some categories of degraded lands (impacts on soils, water use and biodiversity), combined strategies for modernization of agriculture and diversification of cropping patterns (e.g. intercropping, agroforestry systems).

Both in size and in terms of meeting this wide array of criteria, annual food crops may not be suited as a prime feedstock for bio-energy. Perennial cropping systems, however, offer very different perspectives. These cannot only be grown on (surplus) agricultural and pasture lands, but also on more marginal and degraded lands, be it with lower productivity. Such cropping system represent a very diverse set of possible production systems, from low intensity forestry like operations and managed existing grasslands, up to highly productive plantations with short rotation coppice systems or energy grasses like *Miscanthus*. At this stage there is still limited (commercial) experience with such systems for energy production, especially considering the more marginal and degraded lands and much more research and demonstration work is needed to develop feasible and sustainable systems suited for very different settings around the globe. This is a prime priority for agricultural policy.

8. Developing sustainable, international, markets for biomass and bio-energy.

Beside the strong increase in liquid biofuels, trade and production in pellets and other forms of solid biomass is also on the rise. Some examples: Brazil exported in 2005 2.5 billion litres of ethanol with main destinations India (23.1%) and USA (20.2%) (Walter *et al.* 2006). The rapidly changing character of worldwide biofuel production capabilities is also illustrated by recent trends in the United States: In 1995, U.S. biodiesel production was 1.9 million litres; by 2005 this was more than 280 million litres (WWI 2007). Total Canadian exports of wood pellets were around 625,000 tonnes in 2006 (Swaan 2006). The share of imported biomass in the Netherlands increased from 30% in 2003 to 50% in 2004 (mass basis). For co-firing and electricity, the share has increased from 30% to 80% in 2005. Essent, the largest single user of biomass in the Netherlands, reported that approximately 30% of the biomass originated from North America, 25% from Western Europe and 20% from Asia, and 25% from other regions (Junginger *et al.* 2005b).

The development of truly international markets for bioenergy has become an essential driver to develop available biomass resources and bioenergy potentials, which are currently underutilised in many world regions. This is true for both (available) residues as well as possibilities for dedicated biomass production (through energy crops or multifunctional systems such as agro-forestry). The possibilities to export biomass derived commodities for the world's energy market can provide a stable and reliable demand for rural communities in many (developing) countries, thus creating an important incentive and market access that is much needed in many areas in the world. The same is true for biomass users and importers, that rely on a stable and reliable supply of biomass to enable (often very large) investments in infrastructure and conversion capacity.

This market stability and proper governance to secure sustainability of biomass production and trade is however far from achieved. Markets are immature and volatile still.

For market parties such as utilities, companies providing transport fuels, as well as parties involved in biomass production and supply (such as forestry companies), high quality knowledge, clear criteria and identification of promising possibilities and areas are of key interest. Investments in infrastructure and conversion capacity rely on minimisation of risks of supply disruptions (both in terms of volume, quality and price).

The growing production and use of biomass as a renewable energy source has created an international biomass market and leads to increasing trade in biomass resources. International trade in biofuels and related feedstock may provide win-win opportunities to all countries: for several importing countries it is a necessary precondition for meeting self-imposed targets. For exporting countries, especially small and medium developing countries, export markets are necessary to initiate their industries (Zarrilli 2006). The production and harvest of bioenergy crops can result in negative impacts on ecosystems, land-use, socio-economic impacts and GHG emissions (e.g. for transport vs. alternative use on-site). With considerable increase in feedstock and biofuels expected, sustainable production is becoming a key concern and is currently being considered as a possible requirement for market access (Zarrilli 2006).

Setting standards and establishing certification schemes are possible strategies that can help ensure that biofuels are produced in a sustainable manner (WWI 2006). Recently, policy makers, scientists and others have recognized these aspects. Certification is the process whereby an independent third party assesses the quality of management in relation to a set of predetermined requirements (standards). These are mostly formulated as criteria that have to be fulfilled for the certification of a product or a production process. To use criteria for the formulation of a certification standard they have to be operational and measurable. Last years, various efforts have been undertaken as steps towards certification for imported biomass. Key documents in this field are (Lewandowski *et al.* 2005), (Fritsche, U. *et al.* 2006a), (WWI 2006) and (Zarrilli 2006), (van Dam *et al.*, 2008). These studies focus on specific aspects in the discussion of biomass certification and include in their discussion relevant initiatives related to their studies. A study providing an overview of recent developments in sustainable biomass certification is, however, missing but needed due to the rapid developments in the field.

Ultimately, biomass and biofuels can develop into a commodity market. This can have major advantages, such as improved market stability and lower prices. Securing sustainability is now a major challenge. The way in which this is governed is still open and is at a crucial stage: at present still fundamental choices can be made on how bio-energy markets are developed, governed and controlled.

It is therefore also crucial to achieve good international collaboration between countries and international institutions (such as the UN bodies and WTO). Dialogue is important for obtaining support as well as to define the conditions how sustainable biomass production and supply can best be introduced and built in the market. It is clear that not all criteria with respect to land-use, competition, biodiversity, etc. can be met to the highest level on short term. Furthermore, a balance is to be found between what is workable in the market and what is necessary to guarantee decent production and supply of biomass and biofuels.

Lessons can be learned from existing certification schemes. In the past 'strict' schemes were often limited to (very) small parts of the total market volume. In contrast, schemes with 'minimum' standards delivered less guarantees, but they do apply to a far large part of the market in question. The development of sustainable markets (and market share) should therefore be seen as a gradual process. The development and implementation of relatively successful schemes as FSC (for forestry) took a long time and the scheme is still under development. Having a longer term view on certification of biomass and bio-energy seems wise. It is at present still unclear what are the most suited trajectories for implementing broadly supported certification. The current proposal of the European Commission for certification of biomass (and which is still debated at the moment of writing) will be influential internationally.

Tackling all areas of concern for biomass production in concrete criteria, design specification and verifiable indicators is a complex challenge. For a number of areas (most notably land use and competition, biodiversity and some of the other environmental themes) no existing procedures and protocols are yet available. The complexity is enhanced by the large (potential) number of biomass production systems and

settings that are already important now and ones which can be considered in the future. Other questions emerge around governance of the markets and which players may have the (main) control over matters. A number of countries, the EC and market and NGO based initiatives already emerged. Demand in for example countries in East Asia, such as Japan, will make a major impact on biofuel markets on the short term already. At the same time, the developing demand triggers more and more players and countries to invest. Key examples are Russia and the Ukraine, the Mercosur region, Southern Africa (e.g. countries like Mozambique and Tanzania) and Canada. Support and implementation of certification is thus truly a global issue.

A guard rail for competition for land and with food?

At the moment, none of the proposals for certification of biomass has clear thresholds for e.g. food security and unsustainable shifts in land use. However, in particular the Dutch Cramer proposal has a number of concepts that can be the starting point or a working procedure (based on Cramer, 2007 and a technical note from Faaij, 2007): Competition with food primarily has to do with competition for land and displacement of land use for other cultivations and applications. Below there follows a further consideration on the parameters that are important to make it possible to map out changes in land use. Changes in land use can be considered at various scale levels with respect to:

- the level of the plantation/the production company
- the macro level (this concerns in the first instance the regional, provincial or (federal) state and national level, but if necessary also the supranational/continental and global level). Here it is possible that at the national level no negative effects will occur as a result of shifts in land use, but that they will occur at the local level.

The following data are notably important to map changes in land use:

- A clear description of the kind of biomass that is used, and the possible alternative use in other markets (for instance as food, construction material, fertilizer, cattle feed or medicines). Here a distinction can be made between residual flows, food crops and non-food crops.
- Information on the application of raw materials for the various objectives and shifts among them over time (this is important for commodities with more than one applications, such as vegetable oils).
- Satellite data for the monitoring of (shifts in) land use and vegetation.
- Statistics on land use (generally national and possibly at the level of (federal) state or province).
- Statistic data with respect to (average) yields of crops over time (e.g. using national and FAO statistics).
- Field data, notably for verifying the diversity (or its decrease) in land use.
- Price information on land and food.
- Data on property relations of land and land use rights.

It is not clear in advance if the extent to which effects occur will be acceptable or not. Some illustrative examples:

1. Increase of food and land prices is disadvantageous for consumers, but in many cases positive for farmers. Higher incomes may lead to investments in agricultural production resulting in a higher production. More intensive agriculture (and cattle breeding) production can also entail lower relative environmental costs. The degree to which and the rate at which prices change will, therefore, have to play a part in the assessment of the effects. Its interpretation will in its turn again depend on regional circumstances (such as spending power), domestic regulation and the price developments within the commodity markets.

2. The introduction of biomass crops (for example grasses or trees) and the simultaneous intensification of agriculture and/or cattle breeding will have various effects. Intensification may result in the decrease of biodiversity; but also in a more diverse pattern of land use by the planting of trees, which will, reversely, lead to higher biodiversity.

3. The (partial) replacement of food production by biomass crops may be seen as undesirable at the level of a province. At the national level conventional agriculture may, however, move to areas where this is more efficient and possibly also ecologically better (for instance owing to more suitable soils). Regionally undesirable effects, therefore, need not be a problem at the national level.

For this theme, therefore, there turns out to be no well-tried system available to map out effects and

subsequently to assess them for sustainability. That is why it has not proved possible yet to work out this theme into testable criteria and indicators. Moreover for the monitoring of changes in land use information will be needed at different scale levels. An individual biomass producer will not be able to monitor shifts in land use, when those shifts exceed the level of the plantation and its (immediate) surroundings. Most aspects of this theme must be monitored at higher scale levels (macro level).

Clearly, building practical experience with mapping developments, scientific research and monitoring and combined efforts of macro-monitoring and mapping developments in biomass production areas is necessary. The combined efforts should lead to verifiable indicators and thresholds that can be used to steer (and possibly slow down) developments of bio-energy in relation to land use, food supplies and availability of food.

9. Closing remarks and recommendations

Biofuels are emerging in a world increasingly concerned by the converging global problems of rising energy demands, accelerating climate change, high priced fossil fuels, soil degradation, water scarcity, and loss of biodiversity.

Since most current modern biofuels are made from food crops, concerns about arable land use competition, risks to food security, vulnerable communities, water resource constraints, and deforestation arise. Meanwhile new crop feedstocks are being developed and advanced biofuel production methods using forest, crop, and urban residues, as well as from non-food crops, are also progressing, but have yet to be commercialized and deployed in the marketplace on a large scale comparable with the size of the energy market.

Food versus fuel?

- Recent agricultural commodity price increases for the most part can be attributed to factors unrelated to biofuel production. These are increasing food and fodder demand as such, speculation on international food markets and incidental poor harvests due to extreme weather events. Also, high oil prices and related high costs of fertilizers have an impact on the price of agricultural commodities.
- Low productivity in agriculture in many regions has resulted in unsustainable land-use, erosion and loss of soils, deforestation and poverty. Increased productivity over time as a result of better farm management, new technologies, improved varieties, energy related capital investment and capacity building would gradually increase the intensity of land use so that sufficient land becomes available to meet the growing demand for food, feed, fiber and biofuel production.

Can biofuels support the agricultural sector and help meet the goal of sustainable development?

- Commercial biofuels markets could become a major factor in raising the economic viability of rural enterprises, especially in developing countries. Increased investment in infrastructure for biofuel processing, distribution and transport would also result. At least some of this infrastructure will also contribute to the overall development of the agricultural sector
- “Second generation” biofuel technologies produced from non-food ligno-cellulosic feed stocks are expected to become commercially viable on large scale, and hold considerable promise, compared to “first generation” biofuels, particularly for expanding the energy base and providing significant GHG emission reductions.

Over time, first generation biofuels are likely to become more GHG efficient and co-exist with second generation biofuels as they are further developed. Tropical and sub-tropical regions will continue to enjoy comparative advantages in producing cost effective feedstocks for both.

Many countries have a competitive advantage in producing biofuels. Meanwhile, many other countries are unable to meet their biofuel needs from domestic sources. Therefore, increased biofuel trade holds promise. Also, when bioenergy displaces fossil fuels, in transport and power generation, or is produced in conjunction with soil carbon storage in the form of bio-char for example, opportunities arise for trade in carbon emission reduction units.

Most challenging in harnessing biomass production potentials in a sustainable way is probably the design of governance and implementation strategies. Such strategies should allow for gradual introduction of biomass cropping systems into rural regions and simultaneously increasing agricultural and livestock productivity. Those productivity increases are an essential component to avoid conflicting claims on land and to strong competition (e.g. via increased prices for food). Policies targeting development of bioenergy use and biomass production should incorporate a variety of targets and boundaries. Fulfilling a strict GHG criterion (e.g. 90% compared to reference fossil energy use) will lead to different choices for crops and land management compared to a situation where no criterion is formulated. This is also true for sustainable management of water resources, biodiversity, as well as rural development. Clearly, the balance of objectives will be different from setting to setting (compare rural Africa with the EU for example) and trade-offs have to be made. It is argued here that such trade-offs should be explicit, balanced and incorporate clear boundaries that should be respected and used as a starting point for developing biomass production in a give region. Governance and deployment of incentives (such as subsidies or obligations) could than also be designed to achieve just that. This is a fairly sharp contrast to some of the current biofuel policies implemented in the EU and the US.

Towards a Sustainable Global Biofuels Market

The current negative image of biofuels in some quarters, provoked in part by a rather complex set of national public support schemes, is threatening the fulfillment of their promise and must be addressed. Paramount to a solution is an orderly and defined schedule for elimination of subsidies, tariffs, import quotas, export taxes and non-tariff barriers in parallel with the gradual implementation of sustainable biofuels mandates. These measures will provide the necessary conditions to reduce risks and to attract investment to develop and expand sustainable production. Several different efforts to reach these goals are ongoing including multilateral, regional, and bilateral negotiations, as well as unilateral action. Ad hoc public and private instruments such as standards and product specifications and certification may also prove useful for addressing technical and sustainability issues. In addition, the development of a global scheme for sustainable production combined with technical and financial support to facilitate compliance, will ensure that sustainability and trade agendas are complementary.

Actions and Stakeholders

Integrate and better coordinate policy frameworks, this requires:

- coordinating national and international action among key sectors involved in biofuel development and use, including agriculture, energy, environment, transport;
- negotiating a schedule to gradually eliminate the tariff and non-tariff barriers to biofuels trade;
- agreeing on internationally compatible fuel quality technical standards whilst recognizing that several countries are already engaged in efforts to harmonize these standards;
- transparency in blending and other regulatory requirements at national and sub-national levels;
- reviewing policies in agriculture, energy and other sectors that contribute to inefficient production and market distortions in biofuels and their feedstocks; and
- adopting local, bilateral, regional and/or other frameworks for biofuels trade agreements with the objective of collaborating with existing frameworks (for example the UN Framework Convention on Climate Change; and the G8 established Global BioEnergy Partnership) to achieve convergence towards a comprehensive international land use improvement agreement.

Assess benefits and impacts of biofuels trade, use and production, and monitor them, this requires:

- agreeing on sustainability principles and criteria that include effective, mutually agreed and attainable systems, via means such as certification, consistent with World Trade Organization (WTO) rules;
- recognizing that several key international efforts are already underway both in governmental and non-governmental contexts and that an iterative review of such criteria should be undertaken in order to continually raise the standards through advances in knowledge from research and through experience gained in the field;
- harmonizing life-cycle analysis - LCA - methodologies for biofuels, including GHG life-cycle accounting methodologies, recognizing that efforts both at the international and national levels are already under way;

- continued mapping of degraded and marginal land; and
- continued mapping of carbon stocks, areas rich in biodiversity, and other high conservation value areas. Transparency, accessibility and application of these maps need international agreement and must have sufficient resolution such that small scale farmers are not excluded. It is recognized that efforts to map carbon stocks are being stimulated by the IPCC and undertaken by several other global land use mapping organizations but they must be better coordinated.

Addressing indirect impacts explicitly requires:

- continued global research to identify and quantify links between biofuels and land use change;
- mechanisms to promote biofuels that do not have negative land use change impacts;
- mechanisms that mitigate these negative impacts but do not unduly increase transaction costs for producers; and
- social safeguards, at national level, that ensure that vulnerable people are not disadvantaged through food and energy price increases and other potential negative economic side effects.

Reward positive impacts and investments, including through carbon management

Enhanced market opportunities will open up capital in order to follow the most profitable business models. Some benefits from biofuels use do not have an associated income stream. Therefore even sustainable trade as outlined in this document will not necessarily flow to the best performers. Under-funded benefits fall into the categories of:

- rural and social development;
- ecosystem services, including biological carbon fixation and water resource management; and
- better practices that might reduce crop yields but restore ecosystem health, such as conservation agriculture.

Rewarding better practice will require:

- using existing and innovative tools to ensure that markets reward environmental and social performance, including carbon sequestration, without additional requirements;
- recognizing that the post-Kyoto regime will possibly reward biological carbon fixation, and this should be encouraged;
- ensuring that biofuels development is accomplished by shared benefits, rights and rules of law;
- recognizing that biofuel projects that create significant rural and social development benefits will likely be under-invested in due to difficulties in integrating smallholders into markets, tendencies to concentrate buying power within supply chains, and a lack of financial markets for small producers;
- understanding that many business models exist that equitably share benefits throughout the supply chain, especially at the farmer level. National policies, bilateral agreements, foreign assistance, and international financial institutions should give preferential treatment to these types of production systems to the extent feasible and to projects that encourage development of small scale production and regional biofuels markets; and
- acknowledging the link between bioenergy and rural development for improving rural incomes and abating poverty, improving food security and thus providing a basis for increased investment and more efficient and sustainable agriculture.

Use informed dialogues to build consensus for new projects

Promoting an informed and continuous dialogue engaging all relevant stakeholders is key to ensuring equitable distribution of benefits of biofuel projects, and to addressing other elements of sustainability. It is particularly important to encourage biomass producers, both farmers and foresters, into the dialogue. To be effective, these dialogues must be translated into the allocation of public and private budgets to meet the consensus achieved on priorities for specific projects and R, D & D portfolios.

Increase investment in research, development and demonstration

While countries could consider other climate related initiatives besides biofuels, the goals of public and private R, D&D investments related to biofuel trade, use and production should include (but not limited to):

- to produce cost effective second generation biofuels;
- to use sustainability lessons from first generation biofuels for second generation;

- to increase conversion technology performance;
- to maximize climate change mitigation;
- to increase crop productivity and improve ecosystem health through management techniques, improved mechanization, water management, precision farming to avoid wasting fertilizers and agro-chemicals, and plant breeding and selection.

Build capacity to enable producers to manage carbon and water

Capacity building programs are needed for farmers, foresters and small and medium-sized enterprises active in bioenergy and biosphere carbon management systems, such as biochar soil improvement techniques and water management technologies. Capacity building is also needed for the development of effective technology innovation systems involving research and education, extension, industrial capacity to participate in joint ventures with supportive government agencies and an engaged civil society.

Make sure that trade policies and climate change policies work together

There is a need for a clear commitment for national climate change policies, including those that promote biofuels, to be additional to ODA (Official Development Assistance). This is best achieved by climate change policies that drive direct foreign investment by energy sector players, in harmony with trade policies and sustainability requirements. Guided by national stakeholders' consensus, ODA should focus on helping to initiate and develop the institutions needed for sustainable rural development and respective business models, and support countries in defining and meeting sustainability requirements. In connection with biofuels development, ODA should also partner with development and UN agencies such as UNFAO, UNCTAD, UNDP, UNEP and UNIDO and the private sector to help in reducing transaction costs of sustainable development schemes.

If indeed the global bio-energy market is to develop to a size of 400 EJ per year over this century (compared to 470 EJ current total global energy use), which is quite possible given the findings of recent global potential assessments, the value of that market at US\$ 4/GJ (considering pre-treated biomass such as pellets) would amount to some US\$ 1.6 trillion per year. Logically, not all biomass will be traded on international markets, but such an indicative estimate makes clear what the economic importance of this market can become for rural areas worldwide, as are the employment implications. Considering that, very roughly, a quarter of the abovementioned 400 EJ could be covered by residues and wastes, another quarter by biomass production schemes that regenerate degraded and marginal lands, and the remaining half from current agricultural and pasture lands, some 1 billion ha worldwide may be involved in biomass production. This is some 8 % of the global land surface and one-fifth of the land currently in use for agricultural production.

The opportunities for developing regions are evident. There is also agreement on the need for safeguards to avoid too rapid growth and unsustainable practices. Certification, preferably starting from an internationally accepted framework but developed, applied and verified in detail at a regional level with strong stakeholder participation, seems to be a crucial way to achieve that.

It is in developing countries that the possibilities and potentials for modern bio-energy production, including export, are largest and at the same time the need for development of rural areas is the highest. These crucial issues, global bio-energy markets and rural development, merge in a formidable way. This sheds a new light on the bio-energy option; bioenergy should be seen as a global energy commodity and the fact that we are seeing the market really develop in this direction makes clear that we should better prepare for this. Given the scale of the market, bio-energy trade could provide one of the most important sustainable development pathways for decades to come: developing bio-energy as the key sustainable and carbon-neutral alternative to fossil fuels and at the same time mobilising rural areas around the world into becoming key energy producers and exporters could contribute to poverty alleviation and further development.

There are also many barriers that could disturb or at least slow down a sound development of such markets. Moreover, there are important concerns about competition for land that may be in conflict with food production, water resources and biodiversity protection. Although biomass production may well provide a crucial strategy to enhance sustainable land-use management, negative developments should be avoided, e.g., by clear standards and best-practice guidelines for (the design of) biomass production systems and their integration in agricultural areas. Gaining experience with certification, developing the desired

international frameworks, removing trade barriers and showing best-practice operations through export-oriented pilot projects in a diversity of developing countries and different rural areas are crucial in the short term. Good examples, successful business models and sound sustainability frameworks can guide market forces in a sustainable direction.

Coming back to the dilemma with which this paper started: biomass and its use for energy and materials can indeed play a major role in the future world's energy energy and material supply. But it won't be easy. For various actors the complexities around biomass and sustainability are a reason to shy away from it. But we can't afford that. The number of problems that need to be tackled simultaneously is too large and too vast and do not allow for skipping options. We need them all. In particular options that can merge different key objectives when done right.

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