Journal of Agriculture and Rural Development in the Tropics and Subtropics
Volume 110, No. 1, 2009, pages 75–91

Agricultural Research for Development in the Tropics: Caught between Energy Demands and Food Needs

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Keywords: biofuel,

1 Introduction

The use of plant biomass for fuel is almost as old as mankind. However, a continuously growing population and the increasingly rapid exploitation of both fossil fuels and natural resources such as soil, water and biodiversity, have stimulated a debate of how to balance the needs and demands for food, feed, non-food raw materials and most recently energy in agricultural systems. Against the background of the current population growth, mankind faces the problem that the global system is closed and the available resources are finite. Energy is the only resource constantly supplied to the system from outside. All energy resources available on earth are in one way or the other transformations of one of the four following: a) solar energy - which can be exploited directly, is transformed into biomass by photosynthesis, and drives the global wind and water cyle, b) tidal force owing to gravitational pull between earth and moon, c) the earth's internal heat exploited as geothermic energy and d) nuclear energy. Of these, solar, tidal and geothermic energy are energy sources, which are not finite in time periods humans can still grasp. Based on data on fossil fuel reserves and consumption figures from the BP Statistical Review of Energy 2008 (BP, 2008), MACHANIK (2009) calculated the time when fossil fuel expires as 2208 at constant consumption, about 2082 at an energy consumption growth rate of 2.4% per annum, which was the growth rate from 2006 – 2007, and at about 2057 at a more progressive growth of energy consumption of 5% per annum. There is therefore an urgent need to invest in research and development for the exploitation of renewable energy sources, on the other hand we face the situation, that for whatever reason it does not seem possible at the moment to tap fully fledged into the energy resources listed above. Politicians globally rather propagate to include varying percentages of energy derived from plant biomass into their countries energy mix and that is where the devil is in the details. The debate on biofuel versus food production is well illustrated by two recent public statements:

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According to Agence France-Presse on March 23rd 2008, the head of Nestlé - the world's largest food and beverage company - CEO Peter Brabeck-Letmathe said, "If as predicted we look to use biofuels to satisfy twenty percent of the growing demand for oil products, there will be nothing left to eat. To grant enormous subsidies for biofuel production is morally unacceptable and irresponsible" (Tenenbaum, 2008).

"FAO's latest forecast for world cereal production in 2008 points to a record output, now at nearly 2,192 million tonnes, including milled rice, up 3.8 percent from 2007. Among major cereals, the tight wheat supply is likely to improve most, given the prospects for better harvests in 2008. Despite record production levels in several crops, tight markets will probably lead to continued price volatility during the season" (FAO, 2008).

These two statements show the inherent dilemma of this discussion. On one hand the productive land area continues to be increasingly productive. On the other hand people claim without any substantiating data that producing a considerable share of the world's energy demand as biofuel will take food off the tables. We will try to disentangle some of the arguments in the following.

Agriculture uses cycles that are - or rather should be - more or less closed. Producing harvestable goods from plants on the one hand requires nutrients and water to be fed into the production system and, on the other hand, entails the export of nutrients and water from the system with each harvest. If food, animal feed, raw materials and energy have to come from the same production system, the input/output balance for essential production factors becomes crucial. Since a few years there is a public debate going on, whether the increased production of biofuels poses a threat to food production or not (Rosillo-Calle, 2005; Doornbosch and Steenblik, 2007). One of the problems in this context is that the discussion is lacking behind the actions already taken in many agricultural sectors, particularly in tropical countries. Biofuels got their first boost, both in terms of production area and political support during the OPEC oil embargo in the seventies of the last century, followed by the urgent need for a simple solution to global warming and CO_2 emissions in the late 90ties (Clancy, 2008). This lead to a large number of convictions and arguments that to a large extend were not substantiated by more than one doubtful source, however none the less, forming public opinion.

It appears that there cannot be a general conclusion that the production of biofuels or renewable resources negatively influences food production. In fact, the issue has to be evaluated with the respective context in mind. Thus, some authors emphasise the fact that first generation biofuels due to political inventions have been just subverted from the food sector, which in some cases produced a shortage in food grain, that was reflected in the prices for raw materials (Naylor *et al.*, 2007), but that in no case lead to a real food shortage (Bricas, 2008). An analysis of the recent publication on this issue clearly showed that the problems need to be studied from several angles at the same time and interactions with other factors such as oil price, climate change, subsidy policies, as well as political goals need to be included in the overall picture. In the following we will try to look into some of the issues and how they are seen in the current scientific debate. We will start by listing, based on the existing literature, arguments usually given for and against energy production from biological resources (Table 1)

Table 1: Positive and negative effects of increased biofuel production as seen in recent publications.

Pro	*Contra*
• Creates new jobs[1] • Increases economic growth[1,2] • Reduce greenhouse gas emissions[3,4,5] • Is CO_2 neutral[3] • Marginal lands can be brought back for production • Increases rural development[6,2] • Provides locally grown ernergy[1] • Provides energy security • Improves the trade balance	• Destroys environments[4] • Increase food shortages[7,8] • Reduces water availability for agriculture[9] • Increases the poverty gap • Competes for land[9] • Is too expensive • Increases greenhouse gas emissions • Pollutes environments

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[1]: JENNER (2008), [2]: LAURSEN (2007), [3]: GOMEZ *et al.* (2008), [4]: FARGIONE *et al.* (2008), [5]: ZAH and LAURANCE (2008), [6]: RAJAGOPAL (2008), [7]: PUCKETT (2008), [8]: WATKINS (2008), [9]: DE FRAITURE *et al.* (2008).

Depending on which angle is used to look at the biofuel vs. food issue, different conclusions can be drawn whether increased biofuel production is a positive or a negative development. Some of those viewpoints will be summarized below.

2 The Political Angle

Whether there is a strong incentive to grow fuel instead of food is in most cases driven by political decisions and subsequent subsidy policy, and policy makers set the courses for food and biofuel production at global, international and national level. Achieving the 2015 Millennium Development Goals (MDG) adopted by the United Nations General Assembly in 2000, which include halving the world's undernourished and impoverished, lies at the core of global initiatives to improve human well-being and equity (UNITED NATIONS, 2008). Yet to date, virtually no progress has been made toward achieving the dual goals of alleviating hunger and poverty at the global level, although the record varies on a regional basis: Progress has been made in many Asia-Pacific and Latin American-Caribbean countries, but has been mixed in South Asia, and setbacks have occurred in numerous sub-Saharan African countries (FAO, 2006; DEATON and KOZEL, 2005). Whether the biofuels boom will move extremely poor countries closer to or further from the Millennium Development Goals remains uncertain. The discussion on the possible impact of biofuel production on global political projects such as the MDGs was recently comprehensively reviewed by NAYLOR *et al.* (2007). One of the driving factors for the promotion of biofuel is the strongly felt need to stay mobile. Most calculations show that the energy demand in 2050 can be amply met by combining wind, solar, hydro and biomass power independent of the population growth scenario (e.g. (De Vries *et al.*, 2007). However, most of the energy produced from regenerative sources is in the form of heat or electric power and does not yield fuel to be used in mobile combustion engines - and mobility still relies on combustion of liquid fuels. Alternative mobility technologies such as high velocity electric engines or hydrogen fuel cells are far from being ready for serial production. Therefore, in the light of increasing consensus about the end of relatively cheap fossil fuel, the greenhouse gas emissions and resulting global warming and the need for new incentives for the agricultural sector (Rajagopal, 2008), biofuels were initially hailed with enthusiasm as the easy way out of the dilemma. Bioethanol and biodiesel. presumably CO_2 neutral, are liquid fuels usable for cars apparently easy to have with - for the first time in years - a promising income opportunity for the agricultural sector, and at the same time seemed to provide an opportunity for rural development in developing countries possibly benefiting also the poorest population strata. Consequently, political decisions such as the replacement targets for fossil fuel by biofuels of the EU (from 1% now to 10% in 2020) and the US (from 4% now to 20% by 2020) have created a boom for biofuels. Therefore, biofuel production has entered the large scale implementation phase before impacts on landuse, water, climate, ecosystems and social systems were soundly investigated and before mechanisms to avoid eventually associated risks and damages could be implemented (BMZ, 2008; Boswell, 2007).

3 The land use angle

The production of biomass to generate fuel requires land and the most controversial aspect of the current biofuel discussion is the competition of biofuel production with food production for scarce land resources and the associated threat for global food security.

The global land area 130×10^6 km^2 in 2005 consisted of about 15×10^6 km^2 cropland, 34×10^6 km^2 natural grassland, 39×10^6 km^2 forest and 41×10^6 km^2 so called unproductive land. The global agricultural land area has increased from about 12×10^6 km^2 in 1961 to about 15×10^6 km^2 in 2005, which corresponds to an annual increase of about 70.000 km^2 (FAOSTAT, 2008). At the same time, about 100.000 km^2 of arable land is lost every year through degradation (Millennium Ecosystem Assessment, 2005). This implies that even under the current food and biofuel production ratio and even under the currently achieved production levels and increases in land productivity, natural ecosystems are converted into cropland every year at a rate of 170.000 km^2. However, regional differences exist and while over the last two decades cropland area decreased in the southeast of the USA, in East China, in parts of Brazil, and Argentina, it increased in parts of South and Southeast Asia, East Africa, the Amazon, and the American Great Plains at the expense of forests and natural grassland (Millennium Ecosystem Assessment, 2005). With a global population of about 6.3 billion in 2005, the cropland available per person was 2.400 m^2 as compared to 3.250 m^2 in 1975 (FAOSTAT, 2008). If the global energy demand is to be met from renewable resources latest by the end of next century - of which for now at least the liquid fuel demand for mobility will have to be provided from biomass - the cropland area must drastically increase, drawing from the available other land resources, while at the same time accommodating the increasing demand for cropland for food production. In this context, the question arises how much land is required and which land should be and is going to be used.

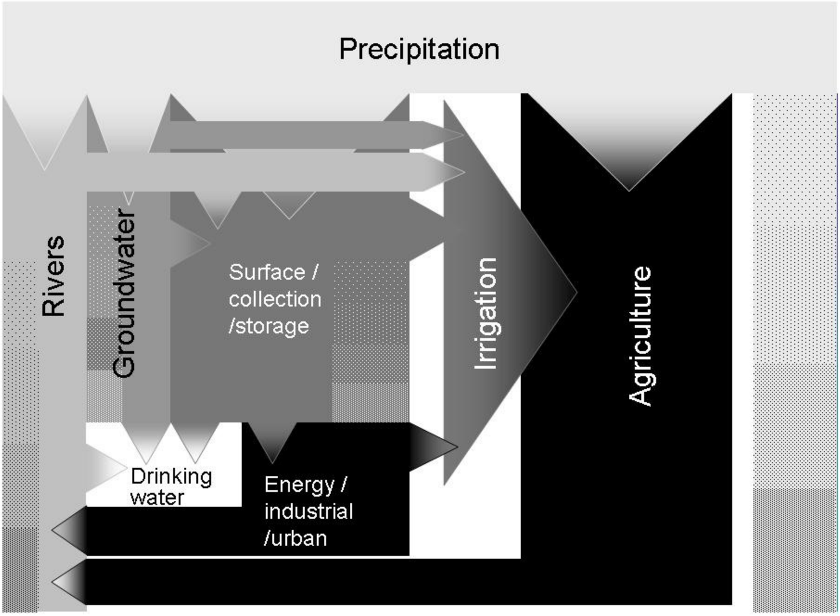
Estimates for potential energy gains from bioenergy or biofuels often stress the point that land used for the production of biofuels is either not prime agricultural acreage, or marginal or degraded (Dale, 2007). However, the definition of which land is marginal is not always easy or straight forward (Asch, 2008), even if such land actually happens to be free or unused. In fact, certain simple assumptions should be applied as to which land is suitable when calculating the potential for biofuel production. For example, irrigated crop land which is highly productive for the food sector should not be considered for biofuel production. Land, on which large stocks of carbon are fixed, namely forests, should likewise not be converted. The issue of carbon release due to land use change is discussed below under the climate angle. All land under environmental protection, national parks and similar areas are not free to use if international conventions or agreements such as the CBD or the Agenda 21 are to be adhered to. The ecological requirements of the biofuel crop in terms of water use and temperature need to be considered. An example calculation for Madagascar based on Jatropha curcas by Asch and Rajaona (2008) demonstrates that less than 3% of the theoretically convertible land would suffice to produce the same amount of bio oil as the nations crude oil imports amount to today. The calculation of the potential area became uncertain where land use rights or land titles were concerned. Vast areas in the tropical and subtropical savannah zone consist of land that is often classified as “degraded grassland”, but is, however, home to herders and grazing ground for the millions of animals from which these societies derive their livelihoods.

Hoogwijk *et al.* (2003) explored the global potential of biomass for energy in a rather complex approach considering i) future food demand, ii) population growth and future diet composition; iii) type of food production systems, iv) productivity of forest and energy crops; v) increased use of bio-materials, vi) availability of “so-called” degraded land, and vii) competing land use types. They differentiated energy crops from cropland and from degraded land, agricultural and forest residues, animal manure, organic wastes and bio-materials as potential biomass sources. Assuming a scenario with moderate dietary requirements and low population growth would leave a maximum of about 26 $\times$ 100^6 km^2 for bioenergy production of which between 4.3 and 5.8 Mio km^2 would be so-called degraded land. The resulting geographical potential of biomass energy was found have an upper limit of 1.135 EJ a^{-1}. However, to produce and provide this amount of biomass, considerable transitions in meat and diary production in developing countries, changes in consumption patterns, and increases in agricultural productivity must be achieved. Hence, policy would first need to address the efficiency of food production systems if land were to be liberated for biomass as part of the future energy mix (Hoogwijk *et al.*, 2003). The study, however, did not consider the competition of food and biomass production for land and possible resulting price increases for food. This increasing competition is today widely acknowledged by many authors and has found its way into policy (BMZ, 2008). Under an aggressive biofuel growth scenario with productivity change and cellulosic conversion technology improvements, price increases in the order of 23% for maize, 16% for wheat and 54% for cassava are predicted until 2020 (ROSEGRANT *et al.*, 2006). At the same time the authors acknowledge "some uncertainty about the timing of eventual large-scale use of cellulosic conversion technologies for biofuel production". Calculations of the International Food Policy Research Institute IFPRI assume an additional 16 Million people - particularly the urban and rural poor in developing countries - threatened with hunger for every percent increase in food prices (BMZ, 2008). The above suggests that the current enthusiastic promotion of biofuel constitutes a major drawback for the international efforts to combat hunger and poverty.

4 The Water Angle

Production of biomass - in contrast to hydropower - is a consumptive use of water based on agricultural activities that may compete directly with food crop production for both water and land resources. Despite the enormous potential for hydropower - e.g. Africa's potential is estimated at 1,750 TWha^{-1}, with only about 5% being realized until today (BMZ, 2007 quoted from MCCORNICK *et al.*, 2008) - biomass has the lions share in renewable energy sources, namely 77% of the total 13% of renewable energy sources in global energy supply (MCCORNICK *et al.*, 2008). However, biomass production requires a large share of valuable natural resources, particularly water and soil borne nutrients. Pursuing biofuel production in water-deficient countries will put pressure on an already stretched resource, creating a major threat to water sustainability. DE FRAITURE *et al.* (2008) estimate that on global average it takes about 2,500 L of crop evapotranspiration and roughly 820 L of irrigation water withdrawal to produce 1 L of biofuel, but regional variation is large. Regional variation, constraints and opportunities for different regions of the world, based on available and used water resources have been recently reviewed by DE FRAITURE *et al.* (2008) and MCCORNICK *et al.* (2008). Depending on which pool the water is drawn from, different users compete for the available water resources. Rainfed biofuel production will either compete with existing rainfed systems in its production (Fig. 1), or in the case where biofuel is produced on marginal or degraded lands, less water will be available for environmental services. Using deep rooting perennials to produce biofuel may tap into ground water resources. Annual biomass crops will change land use patterns and thus affect infiltration, percolation properties, surface water movements and replenishment of surface water bodies such as lakes or reservoirs and thus alter the agriculturally relevant part of the water cycle (Fig. 1) to an extent yet unknown. Converting existing rainfed food crop systems to biofuel production will displace food production to less suitable areas, thus not only increasing pressure on the green water resource but also on land resources (MCCORNICK *et al.*, 2008), with the same aforementioned effects on the water cycle. Irrigated biofuel crops such as sugar cane tap into the irrigation water pool (Fig. 1) and divert irrigation water from food production to biofuel production. This will put additional pressure on surface water reservoirs, and thus also on ground water resources and rivers used for irrigation. In the long run, this may lead to a water shortage in non-commercially used lands which may have yet un-quantified detrimental effects on the environment and, in addition, may affect the availability of water for energy production with hydro power as it may influence the discharge rates of rivers.

Figure 1: Conceptual diagram of rain water receiving and water using compartments within the agriculturally relevant part of the water cycle. The size of the compartments is not proportional, since the proportions would depend on the respective local situation. Pattern shading indicates an amount of water available for environmental services. For the interpretation please refer to the text.



De Fraiture *et al.* (2008) estimate that an additional 30 Mha of crop land will be needed along with about 180 km^3 of irrigation water if all national policies and plans for biofuels are successfully implemented. These estimates do not take into account that the feed stock for biofuels is likely to change from first generation agricultural crops with high land and water intensity to second generation feed stocks that are probably less land and water intensive. So far neither the conversion technology nor the models estimating the resource use base are sufficiently far developed to allow for solid evaluation scenarios.

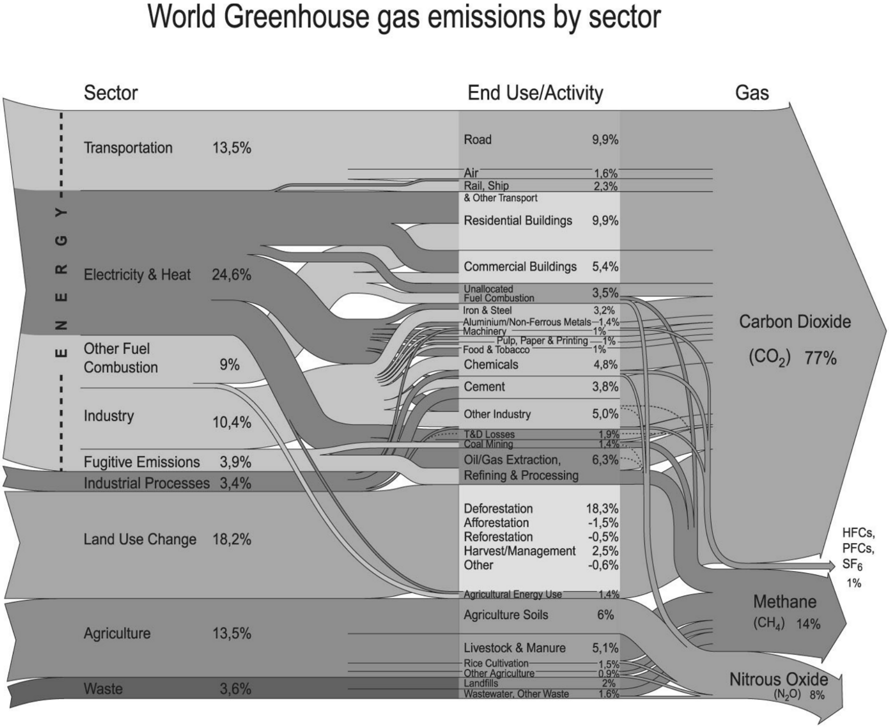
5 The Climate Angle

Whereas biofuels are often claimed to be reducing greenhouse gas emissions, again the view point becomes important. Initially biofuels were believed to considerably reduce greenhouse gas (GHG) emissions as the CO_2 released into the atmosphere during their combustion was previously transformed via photosynthesis from the atmosphere into plant biomass. However, the production process for biomass leads to additional release of GHG from different sources. As discussed above, production of biomass is associated with land use change – either through natural ecosystems directly converted to biofuel cropping systems, or through biofuel systems replacing food production systems, for which in turn natural ecosystems will be taken under cultivation. Since biofuel crops are grown in monocultures on industrial scale with large space requirements, in many cases, biofuel production has lead to massive deforestation in developing countries (among the most prominent examples are Malaysia, Indonesia and Brazil) or to draining and converting peatlands to establish oil palm plantations. Such massive changes in land use destroy large carbon sinks and lead to releasing large amounts of CO_2 into the atmosphere. Therefore, reductions in GHG emissions through mixing petrol or diesel with biofuels in the developed world are potentially off-set by land use changes in the developing world (Boswell, 2007). The Intergovernmental Panel on Climate Change (IPCC) estimates land use changes to contribute 18.2% to the global GHG emissions in 2000 (cf. Figure 2).

Such land use change associated emissions must be calculated into the overall balance for GHG emissions related to biofuel production as carbon debts. Searchinger *et al.* (2008) and Fargione *et al.* (2008) show that converting rainforests, peatlands, savannas, or grasslands to produce food crop–based biofuels in Brazil, Southeast Asia, and the United States creates a "biofuel carbon debt" of 17 to 420 times more CO_2 than the annual GHG reductions that these biofuels would provide by displacing fossil fuels. For example, maize-based ethanol, instead of producing a 20% saving, nearly doubles GHG emissions over 30 years and increases GHG for 167 years, as farmers worldwide respond to higher prices and convert forest and grassland to new cropland to replace the grain or cropland diverted to biofuels. Another example shows that ethanol produced from sugarcane in Brazil on converted rangeland would pay back the land use change-induced carbon debt only after 4 years. If displacing livestock holdings, which then would convert tropical rainforest into new pastures, bioethanol would have a 45-year carbon payback time (Searchinger *et al.* 2008, quoted by BMZ 2008). Figure 3 below illustrates relative GHG emission values for different biofuel alternatives as compared to fossil fuels.

Due to economies of scale, most biofuel operations in developing countries today are large scale with intensive use of external inputs. Investor's major objective is mostly to maximise the return on capital investment, hence - given the existing price structure for energy, land, labour, and inputs - intensification will occur and biofuel operations will tend to occupy fertile agricultural land rather than degraded marginal areas. Particularly this input intensive agriculture releases mainly nitrous oxide and methane into the atmosphere, with N_2O being an about 300 times and methane about 21 times more ef-

Figure 2: UNEP/GRID-Arendal, 'World Greenhouse gas emissions by sector', UNEP/GRID-Arendal Maps and Graphics Library, 2008, <http://maps.grida.no/go/graphic/world-greenhouse-gas-emissions-by-sector> [Accessed 17 October 2008]

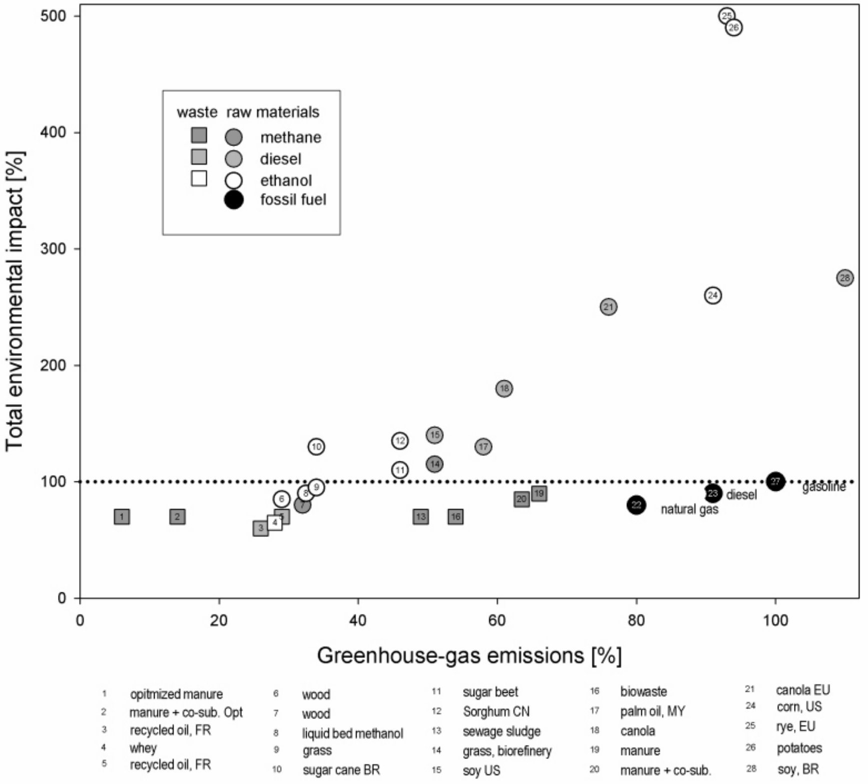


All data is for 2000. All calculations are based on CO_2 equivalents, using 100-year global warming potentials from the IPCC (1996), based on a total global estimate of 41 755 $MtCO_2$ equivalent. Land use change includes both emissions and absorptions. Dotted lines represent flows of less than 0.1% percent of total GHG emissions.

Source: World Resources Institute, Climate Analysis Indicator Tool (CAIT), Navigating the Numbers: Greenhouse Gas Data and International Climate Policy, December 2005; Intergovernmental Panel on Climate Change, 1996 (data for 2000).

fective GHG than CO_2. Further climate relevant GHG emissions associated with biofuel production are caused by the energy consuming production of synthetic fertilisers and pesticides, and by operating farm and post harvest machinery. All such processes add their share to the global GHG emissions (Fig. 2). Recent studies have investigated both the GHG release (Boswell, 2007) and the environmental impact of bio fuel production through over-fertilization, acidification of farmland and loss of biodiversity (Zah and Laurance, 2008). Figure 3 shows, that so called first generation biofuels such as soy, corn, and canola produce about the same level of greenhouse gas emissions as diesel and gasoline from fossil sources, but the environmental impact of those crops can be up to 3 times higher. On the other hand, the study of Zah and Laurance (2008) suggests that second generation biofuels allow for up to 50% reduction of GHG emissions as compared to fossil fuels (Fig. 3). Likewise, biofuels produced from waste biomass or from perennials grown on degraded and abandoned agricultural lands incur little or no carbon debt and can offer immediate and sustained GHG savings (Searchinger *et al.*, 2008; Fargione *et al.*, 2008; Zah and Laurance, 2008). Thus, if reducing GHG emissions is one of the main goals when producing biofuels, policies need to promote such biofuels and processes that do not trigger significant land use changes, are established on marginal lands and do not use fossil fuel derived inputs such as synthetic fertilisers and pesticides (CGIAR, 2008).

Figure 3: Greenhouse gas emissions plotted against overall environmental impacts of 29 transport fuels, scaled relative to gasoline. Fuels in the shaded area are considered advantageous in both their overall environmental impacts and greenhouse gas emissions. Adapted from Zah et. al. (2008).



6 The Energy Angle

Major food crops are being increasingly diverted for biofuel production with the aim of reducing dependencies on oil imports at the national level and to provide easily available energy at local level. One of the questions raised in this context is if biofuels are efficient substitutes for fossil fuels. In terms of land requirements and conversion efficiency different types of feed stock yield different answers to that question. Among the major feedstock crops, biofuel energy yield is greatest for Malaysian palm oil (156 $GJha^{-1}$) and smallest for Brazilian soybean with a 10-fold difference between the two based on current crop and processing yields. On average, the energy yield per hectare from Malaysian oil palm was 1.4-fold greater than the energy yield from Brazilian sugarcane (116 $GJha^{-1}$), 2-fold greater than U.S. maize (79 $GJha^{-1}$), and 4-fold greater than Brazilian cassava (39 $GJha^{-1}$). These figures, however, represent gross biofuel energy yields; they do not account for energy expended in the cultivation, harvesting, and processing of the crops, which would reduce their net energy yields (NAYLOR *et al.*, 2007).

Whereas first generation biofuels from starchy crops are highly inefficient regarding the energy balance and the land requirements (CGIAR, 2008), second generation biofuels, such as forestry and crop residues, corn stover, and switchgras, in contrast require less land resources, due to the vast abundance of biomass crops, that could support a larger bio-fuel industry than food crops alone (NAYLOR *et al.*, 2007). In addition, bio-fuel production from ligno-cellulose holds a significant potential, due to the energy contained in biomass (ROYAL SOCIETY, 2008). The problem to date and the reason for not acting on second generation bio-fuels right away is the current lack of technology. According to NAYLOR *et al.* (2007), ligno-cellulosic biomass to fuel conversion processes are still under development and existing infrastructure such as large scale harvesting, storage, and refinery systems are not yet economically competitive. At the same time, ecological aspects are still being discussed. Whereas the CGIAR concludes that second generation bio-fuels will reduce the pressure on valuable resources such as water and fertilizer, thus creating benefits that will be superior to even the best sugarcane ethanol (CGIAR, 2008).WRIGHT and BROWN (2007) conclude that water and fertilizer requirements may be significantly higher for second generation bio-fuels, than for maize ethanol production.

As often in the biofuel vs. food debate, just integrating the figures on a national or global level, does not capture the actual problem. The rising crude oil price is seen to be responsible for an increased interest in biofuels. Since some major energy consuming countries convert a large share of their food production to biofuel (shown for the US by NAYLOR *et al.*, 2007, for China by DE FRAITURE *et al.*, 2008), they limit exports of grains and start importing food grains from cheaper sources in the developing countries creating food shortages and food price increases there (JAMET, 2008). However, this scenario as convincing as it may look at first glance is not entirely correct. The lions share of the US maize exports for example are received by developed countries where it is mostly used as animal feed. Even on the local market the US used 76% of its maize production to feed animals (MULLER and LEVINS, 2000). For US produced soybean the situation is similar. Thus, there is at least no direct link between food shortages in the developing world and US maize conversion to biofuel. Food price increases in the developing countries have a variety of reasons, among which the most important are production costs depending on crude oil such as fertilizer, transport, and irrigation costs as well as recent crop failures due to freak climatic events (Bricas, 2008). Rising oil prices do disturb the balance in the water-energy-food-environment interface, first of all through increasing water costs that in return will impact on food and on energy prices (Hellegers *et al.*, 2008). This has lead to the Chinese decision to limit expansion into first generation biofuels derived from starchy grains in order to stabilize food prices (BMZ, 2008).

In addition, major focus in the debate is on those countries that started converting vast areas of primary or secondary rainforest into biofuel production areas, either in form of oil palm plantations (e.g. Indonesia), Jatropha plantations (e.g. India) or irrigated sugar cane (e.g. Brazil), thus producing an enormous carbon debt (see also Fig. 3). However, those countries account only for the smaller part of the group of developing countries depending to date to a major share in their energy consumption on wood as fuel for cooking and heating, either in form of charcoal or timber. Traditional biomass remains the dominant contributor to energy supply for more than a third of the global population, mainly living in developing countries (Sagar and Kartha, 2007). For those countries whose energy and CO_2 balance depends to a large extent on wooden fuel, bioenergy in form of either biogas from biomass or oil crops such as Jatropha may make a major difference in environmental and health protection, quite independently of the crude oil world market prices.

Finally, energy production is not the only issue. Most of the energy crops have multiple industrial uses such as chemicals, cosmetics or medicinal purposes. For example currently the production of carbon-containing commodity chemicals is dependent on fossil fuels, and more than 95% of these chemicals are produced from non-renewable carbon sources (Rass-Hansen *et al.*, 2007). This opens a wide range of possibilities for diversification in the production of industrial crops, particularly for developing countries, and this market has not yet even started to be exploited.

7 The Biodiversity Angle

The possible impact of biofuels on biodiversity depends mainly on the location, the production system, the plant species used and on growing/farming practices (e.g. large scale intensive monocultures versus integrated small scale mixed farming with intercropping and/or agroforestry systems). As for the location, two extremes can be observed: a) transformation of native forest (or even biodiversity hotspots) into cropland and b) use of marginal lands with low opportunity costs. Especially when natural forests are converted the loss of biodiversity may be significant (FAO, 2008). With regard to the production system, large scale and small scale systems are the two extremes. Especially large scale monocultures have a high impact on biodiversity. Small scale production of biofuels is often advocated as opportunity for enhanced market and smallholder oriented rural development (e.g. van Eckert, 2008) and may contribute to maintaining biodiversity at the same time. According to Milder *et al.* (2008), diverse, small scale, and decentralised biofuel production systems using perennial tree - shrub - grassland vegetation have the potential to increase landscape heterogeneity and provide plant and wildlife habitats. They may contribute to restoring soil organic carbon stocks and provide long-term carbon sequestration, and may substitute firewood thus reducing the pressure on natural forests. They produce biofuel from native species without irrigation and with low external inputs, and thus maintain water quality and quantity. However, when established in previously natural ecosystems, they may also contribute to simplifying a previously more diverse landscape. In contrast, large scale monoculture production systems run the risk of being detrimental for native biodiversity, often clear native vegetation to install the plantation or compete with food production and increase the pressure to further covert natural ecosystems into farmland. Water- and chemical-intensive production of e.g. corn, soybeans, sunflower etc. as feedstock may deplete and or pollute water resources, with concurrent negative impacts on plant and animal diversity (Milder *et al.*, 2008).

The majority of biofuel is currently produced in large scale systems due to the economies of scale in both the primary production process and in the post harvest processing. To promote small scale decentralised biofuel production systems, institutions such as co-operatives or marketing associations may be an option to pave the way for smallholders to participate in the biofuel markets. Also integrated systems, for instance local integrated food-energy production systems, that combine biofuel, food crops and livestock may reduce effects on biodiversity and through increased waste recycling increase the overall system productivity for food and energy (FAO, 2008, cf. also Hoogwijk *et al.*, 2003).

Milder *et al.* (2008) have analysed the conservation and the livelihood potential of biofuel operations at different scales. They conclude that biofuel production for local use can be successfully incorporated into multifunctional smallholder agricultural landscapes for local use, while they attribute "overwhelming ecological and social risks" to large-scale bioenergy production as petroleum substitute. Certification is often advocated as instrument to render biofuel more environmentally friendly or sustainable (Groom *et al.*, 2008) and this has also found its way into formulation of both development and environmental policies (BMZ, 2008).

8 Conclusions

We have shown in the analysis above, that there is no easy answer to the question: is biofuel out competing food production for natural resources. We feel that when addressing this issue future discussions need to include a broader view on the global consequences of regional and national actions. It is necessary to base decisions not on short-term political or economic arguments but on the long term balance for resources and environmental health, both providing the basis for the livelihood of future generations. Therefore, efforts must be made to calculate the real carbon balance and water foot prints for every item and process involved in the production chains and base decisions on the least detrimental approach to crop and energy production and not on the most economical, which basically means cheapest by today's definition.

In view of the dwindling fossil energy resources, the future global energy demand must be met by a mix of the so-called renewable energy sources latest by the end of this century.

With the risks of nuclear power systems being not entirely controllable and hence low consumer acceptance for nuclear energy, the future global energy mix will have to consist of hydropower, photovoltaic and thermal solar energy, wind energy, geothermal energy and energy generated from biomass. Producing energy from biomass uses land and water resources needed for the production of food and other agricultural commodities and for numerous ecosystem services required by a growing population and continuously further developing economies. Therefore, the main efforts to meet future energy needs must be made with view to rendering water, wind, solar and geothermic energy provision systems more efficient. This has to be the first priority, particularly when stationary energy appliances are concerned. Biofuels, however, will also have to be part of the future energy mix, particularly when it comes to maintaining mobility, as long as liquid transportable high density fuels are required and during a transition period to substitute for charcoal and firewood in rural, low-infrastructure regions of the world. Among the different biofuel production processes and the type of biomass production systems, preference should be given to biofuels produced from agricultural by-products and from waste materials, as these do not require additional natural ecosystems to be converted with the associated environmental impact. Agricultural, forest and animal residues, organic waste and waste bio materials have a maximum energy provision potential of about 100 EJ a^{-1} being roughly 10% of the global maximum for all biofuel sources. If then land is to be allocated to grow additional energy crops, the decision on which land should be used for biofuel production must be governed by calculating balances for the respective scarce resources, particularly water and nutrients, and - needless to say – the system's energy balance must clearly indicate a large net energy gain, which is not always true for today's biofuel operations.

As a start, research for development in the tropics should foremost concentrate on increasing the resource us efficiency of agricultural systems, with land, water and nutrients being the most crucial resources to be considered. As for energy provision, the major research need concerns increasing the energy efficiency of biofuel systems and taking technologies further so as to efficiently convert waste organic materials into liquid fuels in small scale decentralised units. At the policy level, frameworks must be developed so as to assist decision makers to select the biofuel process and biomass production system best suited for their site specific conditions and instruments are required to monitor the biofuel value chain and develop certification procedures to avoid negative environmental and social effects.

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