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The Biofuel Debate – Status Quo and Research Needs to Meet Multiple Goals of Food, Fuel and Ecosystem Services in the Tropics and Subtropics

A. Buerkert *[1] and **E. Schlecht** [2]

Abstract
The current biofuel debate is characterized by concerns about the environmental effects of large-scale biofuel plantations, controversies about GMO-based feedstocks and the recent global food crisis. Predictions for the development of the biofuel sector are either departing from the supply-side or the demand-side, but are mostly based on modelling efforts with an unclear experimental basis and only broadly defined economic settings. Results vary widely and tend to undervalue technical progress in processing efficiency or management-related increases in biomass yields. Moreover, calculations often neglect the impact of climate change, the need for irrigation and processing water, for soil fertility maintenance and the importance of socio-economic issues. Against these shortcomings and in view of several decades to centuries of Ecosystem Carbon Payback Times of most biofuel plantations, their future as a large-scale replacement for hydrocarbons will strongly depend on improved matter conversion efficiencies and successful prevention mechanisms for conflicts over land use.

Keywords: Carbon fixation, Ecological Carbon Payback Time (ECPT), Land ownership, Marginal lands, Water use

1 Introduction

To curb the consequences of the global rise in CO_2-levels and other greenhouse gases resulting from the burning of hydrocarbons and of high crude oil prices worldwide, within the last decade large-scale efforts have been undertaken to better use and further explore the potential of plant-based biofuels in partly replacing fossil energy carriers. Rising food prices culminating in 2007/2008 with widespread social unrest in poor countries of Africa and SE-Asia have reminded political decision makers and scientists of an apparently underestimated dimension of the biofuel debate. Existing concerns about the environmental effects of large-scale biofuel plantations such as sugar cane or soybean in

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Brazil and corn in the United States in combination with controversies about the use of GMO-approaches to increase production efficiencies were suddenly amended by the awareness of rapidly disappearing food stocks. To what degree this scarcity was only temporary, related to speculation and regional crop failure and may thus be overcome by increased investments in agricultural primary production to raise yield levels, or whether it is the consequence of a still growing world population combined with a change in consumption patterns (higher demand of livestock products) is still under debate. However, there now is ample evidence that in many cases biofuel plants do not grow for free on wastelands but directly or indirectly compete with food crops for the same resources such as land, water and nutrients. Focussing on tropical and subtropical countries, this paper tries to briefly summarize the *status quo* of the biofuel discussion and to raise questions for further discussion and definition of research priorities.

2 The contribution of biofuels to alleviate energy scarcity and reduce C-emissions: resource-focused and demand-driven assessments

The available reports on the potential of plant-based biofuels distinguish between resource-focused (supply-side) and demand-driven assessments (demand-side). Thereby the former papers focus on the extent of the total energy resources base and the competition between the different use(r)s of theses resources, such as starch for fuel production *versus* starch for food, or fuel (biomass) production *versus* conservation of soil carbon stocks (Berndes *et al.*, 2003, Figure 1). The latter papers, in contrast, evaluate the competitiveness of biomass-based electricity and biofuels with fossile fuels, regardless of which type of biofuels are used. Most of these analyses are based on modelling efforts with an unclear experimental basis and only vaguely efined economic settings. Thereby the final outcomes vary widely and in most cases do not take into account technical progress in processing efficiency or management-related increases in biomass yields. In their evaluation of 17 such demand- and supply-side scenario studies Berndes *et al.* (2003) forecasted a bioenergy potential of 47 - 450 $\times 10^{18}$ J (EJ) yr^{-1} for the year 2050. For this time period Hoogwijk *et al.* (2005), in their IPCC report-based[1] study, predicted that the largest contribution to biofuel energy (130 - 410 EJ yr^{-1}) will come from plants growing on 'abandoned' agricultural land (Hoogwijk *et al.*, 2003) whereby, alternative uses of and possible conflicts from access rights to such lands are not considered.

Most of these scenario studies focus on forest plantations (pine trees and eucalypts) as the source of biofuel that widely vary in total surface area, followed by dung and cereal residues (Berndes *et al.*, 2003). In this context it is assumed that 500 Mio ha of fuelwood plantations can be successfully established by 2050. In this the use of conventional plant breading and genetic engineering techniques to increase biomass production and conversion efficiencies to ethanol (e.g. metabolic engineering to increase lignocellulosic biomass biosynthesis) is thought to play a major role (Shoseyov *et al.*, 2003; Yuan *et al.*, 2008). It is evident that most of these estimates concerning future forest plantations are (overly) optimistic, emphasising technical feasibilities and neglect-

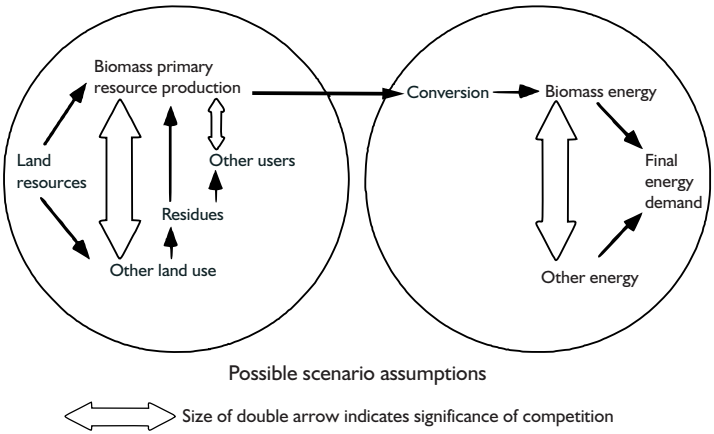
[1] IPCC Intergovernmental Panel on Climate Change; http://www.ipcc.ch/ipccreports/index.htm

ing socio-economic issues such as land use conflicts, timber forest expansions and the effects of climate change, forest conservation efforts and food-first policies.

Another potential and often overlooked constraint to plant-based biofuel production is the large-scale availability of irrigation water, as it is unlikely that all of the above mentioned plantations of trees or crops can indeed be productive on rainfed, low-fertility waste land (Berndes, 2002). In this context it is important to note that total water use per unit of biofuel energy gained not only comprises water required to fulfil evapotranspiration demands during plant production but also for processing steps such as fermentation and waste removal in ethanol production (Frings *et al.*, 1992) or evaporative cooling in power plants.

Less resource-driven and therefore perhaps more reliable seem the estimates of lignocellulose conversion based on crop residues which might reach 270 EJ yr^{-1} by 2100. This would correspond to 75% of the global commercial primary energy consumption in 2000 (Berndes *et al.*, 2003), but major technological breakthroughs are required to make lignocellulose conversion to ethanol economically feasible and operational at the required scale.

Figure 1: Diagram of the difference of demand-driven and resource-focused (supply side) assessments of the potential role of plant-based biofuels. Source: Berndes *et al.* (2003)



3 The likely impact of new technologies on global biofuel production

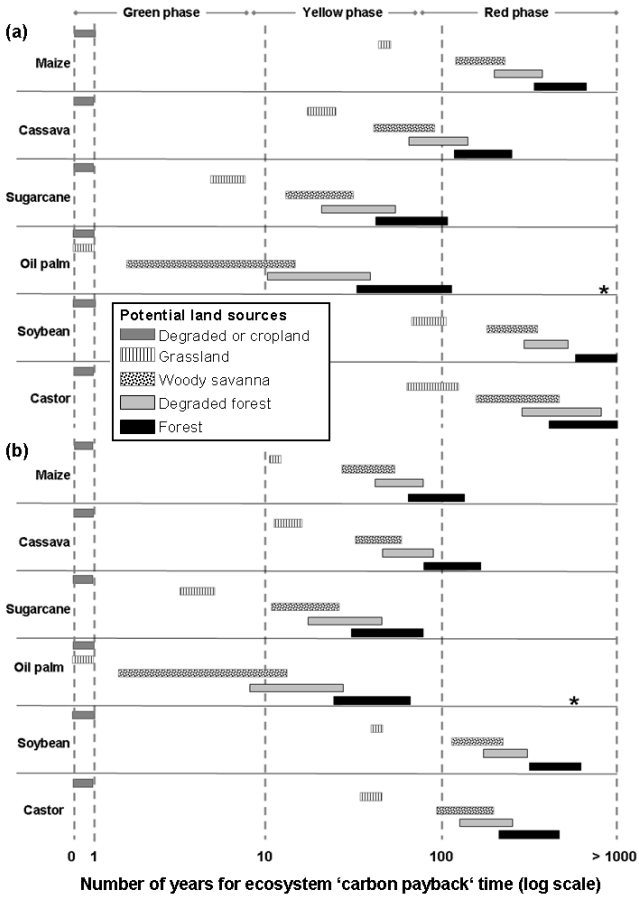
At present biofuels are produced on three pathways or 'platforms' that are ethanol, biodiesel and biogas. Estimated net energy balances vary from 150 - 550 GJ ha^{-1} yr^{-1} for lignocellulosic feedstocks such as poplar (*Populus* spp.), miscanthus (*Miscanthus sinensis*) or switchgrass (*Panicum virgatum* L.), from 10 - 300 GJ ha^{-1} yr^{-1} for ethanol production from maize (*Zea mays* L.), sugarcane (*Saccharum officinarum*), sugar beet (*Beta vulgaris* L.) or sweet sorghum (*Sorghum* L.) but are only -20 - 0 GJ ha^{-1} yr^{-1} for biodiesel production from soybean (*Glycine max* (L.) Merr.), canola (*Brassica napus* L.)

or sunflower (*Helianthus annuus* L.) (YUAN *et al.*, 2008). Among the latter, only sweet sorghum, which is fairly heat and drought tolerant, allows for dual purpose use (grain for food and stover for ethanol production). However, given the much higher biomass yields of switchgrass (10 - 25 t ha^{-1} yr^{-1}) and hybrid miscanthus (7 - 38 t ha^{-1} yr^{-1}; DANALATOS *et al.* (2007) which are even superior to those of poplar and only have a few months of lag time rather than years before harvesting, these two grasses appear to be very promising as biofuel crops. Given its perennial nature, miscanthus has even been used to decrease soil erosion and purify water, and it also contributed to increased diversity of small mammals, birds and invertebrates (SAMSON *et al.*, 2005; HILL *et al.*, 2006; TILMAN *et al.*, 2006; SEMERE and SLATER, 2007a,b). However, future industrial processing of both C_4-grasses for biofuel depends to a large degree on the success of breeding efforts to overcome recalcitrance (particularly due to lignin) and the effective decrease and/or breakdown of lignin. In this context successful genetic manipulation of enzymatic in planta breakdown processes in maize has received particular attention (BISWAS *et al.*, 2006) as well as genetically induced dwarfing (PENG *et al.*, 1997) and increased biomass production by delayed flowering (SALEHI *et al.*, 2005).

4 Food-fuel-ecosystem services: research questions from a system's perspective

One of the approaches to compare the effects of plant biofuel production with non-fuel plant growth and thus an important attempt to evaluate biofuel plant effects on landuse systems is the concept of Ecosystem Carbon Payback Time (ECPT). This consists in calculating the number of years it takes for the biofuel C savings from avoided fossil fuel combustion to offset the carbon losses in ecosystems used to grow those biofuels (FARGIONE *et al.*, 2008). There is evidence that the cultivation of biofuel plants on natural ecosystems such as rainforest areas or drained peatlands may release 17 - 420 times more CO_2 than is saved by the economization of fossil fuel (SEARCHINGER *et al.*, 2008). Based on geographically explicit crop yield data coupled with soil carbon stock data (MONFREDA *et al.*, 2008; RAMANKUTTY *et al.*, 2008), GIBBS *et al.* (2008) showed that decades to millennia of biofuel production would be required to compensate for C losses from cleared tropical rainforests with C stocks of $\sim$200 t C ha^{-1} (as compared to dry tropical forests with $\sim$100 t C ha^{-1}), using even the most effective plant species and processing techniques (maize, cassava or soybean 300 - 1500 yrs and oil palms 30 - 120 yrs on non-peat soils and $>$ 900 yrs in SE Asian peatlands; Figure 2). Depending on C stocks and mineralization patterns even the compensation of C losses on agricultural soils used for biofuel plantations may require several decades. Only the conversion of already degraded lands with low soil C stocks and limited C fixation into biofuel plantations may provide quick C payback, even if to achieve this irrigation and nutrient applications may become necessary (GIBBS *et al.*, 2008). It is obvious that ECPT values also depend on the biomass yields of the introduced biofuel plants; therefore paypack times for many African soils are much longer than elsewhere in the world, due to the predominance of very old, highly leached land surfaces with low productivity. These calculations only slightly change if future needs to partly rely on petroleum sources such as tar sands are considered, of which carbon balances are 17 - 30% lower than of crude oil (BERGERSON and KEITH, 2006; BRANDT and FARRELL, 2007).

Figure 2: Diagram of the ecosystem carbon payback time (ECPT) for potential biofuel crop expansion pathways across the tropics (modified after YUAN *et al.*, 2008). The bars represent the range of ECPT across the humid, seasonal and dry tropics for different combinations of land sources and biofuel feedstock crops. The green, yellow and red column descriptors represent a stop light - where green stands for 'go' in replacing degraded lands, yellow for 'caution' in replacing grasslands, woody savannas and red for 'stop' replacing forests for biofuel crop expansion.
(a) Shows the payback period for potential biofuel production based on crop yields of 2000 as reported in MONFREDA *et al.* (2008). Note that '*' indicates the 918 year payback time if oil palm expands into peat forests. (b) Shows the potential payback period if all crops achieved the top 10% global yields through gradual or abrupt improvements in agricultural management or technology. Yield increases for crops such as maize, castor and rice have the largest impact on ECPT because these crops were substantially below global 90th percentile yields, while sugarcane, soybeans and oil palm were already high yielding so the change has a smaller impact. Note that '*' indicates the 587 year payback time if oil palm expands into peat forests.



Irrespective of ECPT calculations great care should be taken when planning to use large surfaces of 'abandoned land' or 'wasteland' for the production of biofuel plants. Not only does such land often have severe physical or chemical growth constraints for growing biofuel plants, but it may also be exposed to insecurity of tenure and competing uses for its naturally produced biomass by pastoralists whose flocks exploit such open grasslands but are not adequately considered in national and international assessments.

Further neglected constraints for the widespread cultivation of biofuel plants are scale-dependent, such as latent conflicts between large biofuel farmers and small tenants with their subsistence crops.

5 Conclusions

In the wake of increasing competition between biofuel plants and food crops for land, water and ultimately nutrients, the political future of biofuels as a large scale replacement for hydrocarbons will strongly depend on the availability of highly efficient processes for matter conversion into fuel, in particular for the lignocellulosic pathway. Also important will be effective mechanisms to avoid or reconcile conflicts of interest with alternative use(r)s for the land dedicated to biofuel plantations, mainly to avoid competition with plant or livestock-based (subsistence) food production. Finally, small ECPTs are needed to readily obtain positive C balances with biofuel plants as compared to the burning of hydrocarbons and to minimize the generally negative effects of biofuel plantations on (i) natural and agro-biodiversity, (ii) farmers' right to farm their own land for subsistence and (iii) ecosystem services such as carbon sequestration, availability of clean water, prevention of erosion and other effects of multi-dimensional landscapes.

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How Do "Renewable Products" Impact Biodiversity and Ecosystem Services – The Example of Natural Rubber in China

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Abstract
This paper aims to present the implications brought by the expansion of "renewable products" plantation systems in the tropics with cultivation of rubber (*Hevea brasiliensis*) as a main focus. Throughout South East Asia, natural forest is being replaced by rubber or oil palm (*Elaeis guineensis*) plantations, with severe consequences for the local flora and fauna. Main aspects of this review are: i) The provision of an overview over renewable resources in general and rubber in particular, with eco-physiological and agronomical information concerning rubber cultivation. ii) The effect of rubber plantations on biodiversity and species composition under different rubber farming approaches. In addition we debate the possible influences of such large scale land cover transformations on ecosystem services. iii) The conversion of natural forests into rubber plantations releases considerable amounts of carbon dioxide into the atmosphere. We estimated these values for different land cover types in southern China and assessed the carbon sequestration potential of local rubber plantations.

Keywords: biodiversity, renewable products, rubber, ecosystem services, carbon sequestration, ecophysiology

1 Introduction

Ever since, mankind has been dependent on natural resources. From the timber used to build houses to the materials for clothing or the construction of tools, most of these were renewable products obtained from the direct environment. These days, with fossil fuels and minerals to be on the decline, the large scale use of renewable resources is given an increasing degree of importance for a fast-growing human population.

The natural forests of the humid tropics are particularly rich in flora and fauna forming several hotspots of biodiversity. In South East Asia's forests, deforestation rates are highest, mainly because of an increasing agricultural expansion in order to meet the economic and nutritional needs of a growing population. Two of the main contributors are rubber and oil palm plantations. The bulk of rubber plantations in the Greater

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Mekong Subregion replace primary and secondary natural forest, threatening the unique wildlife and disturbing ecosystem services.

In this article, we highlight the possible impacts of large scale use of renewable products with the example of rubber cultivation in South East Asia, especially in southern China. Of particular interest are the implications of the replacement of tropical rainforest by rubber plantations concerning biodiversity, ecosystem services and carbon sequestration potential.

2 Renewable Products

The world demand for renewable resources is constantly growing because of an increasing need by a rising human population. Renewable resources are defined as materials produced by living organisms (plants, animals, microbes) used for purposes other than food and feed. Such materials include timber, natural fibre, oil and grease, sugar, starch, natural rubber, colorants, pharmaceuticals, and others containing special substances like resin, tannin, wax and/or natural protective compounds against pests and diseases (Tab. 1).

Table 1: Selected tropical plants for industrial and energetic use

Plant	*Raw material*	*Final product*
Tectona grandis (Teak) *Swietenia* spp. (Mahogany) *Shorea laevis* (Yellow Balau)	timber	construction wood, furniture, toy, veneer, paper
Agave spp. (Sisal) *Gossypium* spp. (Cotton) *Corchorus* spp. (Jute)	natural fibre	textile, packaging material, carpet, yarn, rope, sack, paper
Elaeis guineensis (Oilpalm) *Butyrospermum parkii* (Shea nut) *Ricinus communis* (Castor oil)	oil	cosmetics, pharmaceuticals, hydraulic fluid, detergent, biodiesel
Saccharum officinalis (Sugarcane) *Siraitia grosvenorii* (Arhat fruit)	sugar	ethanol fuel, pharmaceuticals, cosmetics
Manihot esculenta (Cassava) *Dioscorea* spp. (Yam)	starch	ethanol fuel, pharmaceuticals, detergent
Hevea brasiliensis (Rubber) *Parthenium argentatum* (Guayule) *Manilkara bidentata* (Balata)	natural rubber	tyre, condom, mattress, rubber profile, conveyor belt
Bixa orellana (Annatto) *Lawsonia inermis* (Henna)	colouring	colour, dyeing of leather, hair, fingernails, etc.
Cinchona spp (Quinine) *Rauvolfia serpentine* (Indian Snakeroot) *Zingiber zerumbet* (Ginger)	bioactive chemicals	pharmaceuticals

The cultivation of these renewable resources can contribute substantially to the improvement of a local and regional economic situation but it can also result in biodiversity loss and environmental degradation.

3 Natural rubber as a renewable resource

Natural rubber extracted from the tree *Hevea brasiliensis* (Willd. Ex A. Juss.) Muell. Arg. distinguishes itself from all other raw materials, for it is elastic and at the same time reversible and hence inimitable. To gain rubber the bark of the rubber tree is cut so as to collect the latex, a milky sap from the latex vessels localised in the inner bark. Latex is an emulsion that contains e.g. water, proteins, resins, tannins, and rubber in varying quantities. The Mayas called the tree "Caa-o-chu", that means "weeping tree" (Tab 2).

Table 2: Characteristics of the rubber tree

Name:	natural rubber
scientific name:	*Hevea brasiliensis* (Willd. Ex A. Juss.) Muell. Arg.
family:	Euphorbiaceae
habitus:	tree (may reach heights of more than 20 m within a forest)
fertilisation:	mainly allogamy by small insects such as midges and thrips, autogamy occurs to various degrees
centre of origin:	Amazon basin in South America
natural range:	humid tropics
propagation:	vegetative
first harvest:	5 – 7 years after planting
economic life span:	about 30 years
production unit:	plantation / family farming
predominant constituent harvested:	latex, timber
actual yield of dry rubber:	$\sim$ 3 – 4.5 kg tree^{-1} year^{-1}
potential yield of dry rubber:	about 8.5 kg tree^{-1} year^{-1} (Ong *et al.*, 1994)
major disease:	South American leaf blight of rubber (*Microcyclus ulei* (Henn.) Arx

Not until industrialisation, natural rubber became a basic material. Nowadays, it provides the basis for many high-performance products which we come across in cars, trains, airplanes and ships, in engines and industrial plants. Wherever elastic motion is required and where it is essential to seal, convey, mount, insulate, transmit power or to damp vibration, rubber is of importance.

4 Ecophysiology of Natural Rubber

Hevea brasiliensis is a tropical tree. It grows best at temperatures of 20 – 28°C with a well distributed annual precipitation of 180 – 200 cm. Traditionally, *H. brasiliensis* has been cropped in the equatorial zone between 10°N and 10°S. Urged by a growing world demand rubber has now spread successfully to the latitudes 23°N (China) and 21°S (Brazil) and is cultivated up to 1200 m above sea level (Tab. 3).

Table 3: Characteristics for suitable cultivation of Hevea brasiliensis

	Minimum	*Optimum*	*Maximum*
mean temperature (°c)	<20	25 – 28	34
mean precipitation (cm)	<150	200 – 250	400
rainy season (months)	9	11 – 12	-
moisture deficits (months)	-	0	>3
sunshine (hours d^{-1})	3	6	>7
water logging	-	none	3 days
rooting depth (cm)	>50	>150	-
pH	<3.5	4 – 5	>6
soil carbon (%)	>0.5	>2.5	-
soil fertility	low	very high	-

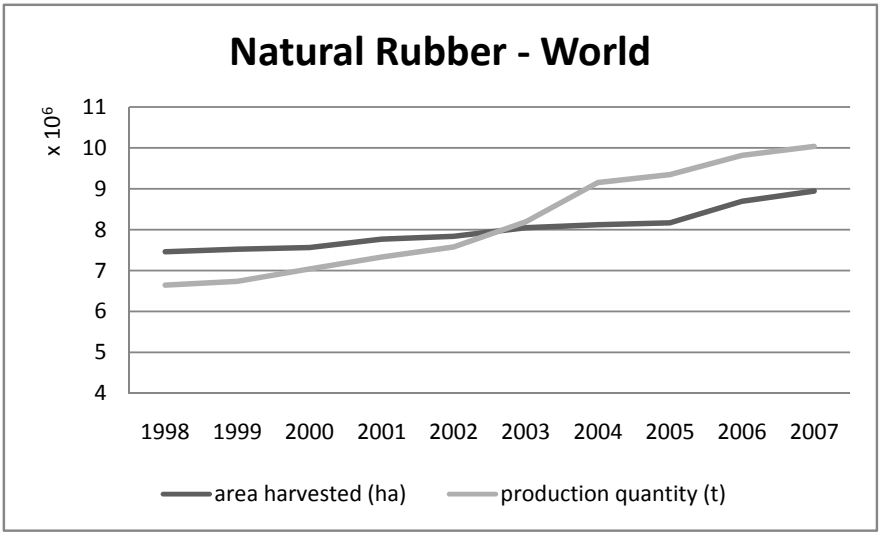
Today, natural rubber provides about 40% of the world rubber demand and is used in the manufacture of over 40,000 products (Ray, 2004). Synthetic rubber, invented at the beginning of the 20th century, covers about 60 % of the current consumption. The world production of natural rubber is constantly growing from about 2 million tons in the 1960s to more than 10 million tons in 2007 (FAOSTAT, 2008) (Fig. 1).

In its centre of origin, the Amazon basin, H. brasiliensis is consistently endangered by the fungus Microcyclus ulei (South American leaf blight of rubber). The pathogen so far inhibits plantation growth of rubber trees in South America (Lieberei, 2007). Beneficiaries of this situation are located in South East Asia where the fungus has not spread to date. Thailand, Indonesia and Malaysia are the main rubber producers followed by Viet Nam and China (FAOSTAT, 2008) (Tab. 4).

Table 4: Major natural rubber producers of the world (data of 2007)

Country	*Area harvested (1000 ha)*	*Yield (t ha^{-1})*	*Production quantity (1000 t)*
China	475	1.1	545
Indonesia	3175	0.8	2540
Malaysia	1400	0.9	1270
Thailand	1763	1.7	3122
Viet Nam	512	1.0	550

Figure 1: Natural Rubber – World (Source: FAOSTAT, 2008)



Microcyclus ulei remains the Achilles' heel of natural rubber production. Not only that its introduction to South East Asia would cause an economic loss to the producers but it would precipitate a crisis within the many industries (medical, transportation, defence, etc.) which are dependent on natural rubber in the manufacturing of their commodities.

Rubber production systems and the conservation of natural biodiversity Natural forest vegetation in the humid tropics is dwindling in an alarming rate, and the loss of biodiversity due to the decline of such habitats is a well-known fact. The level of deforestation in SE-Asia is the highest among tropical areas (Sodhi *et al.*, 2004). The major reason for this is the increasing agricultural expansion, especially due to oil palm and rubber cultivation.

The expansion of rubber plantations in SE-Asia largely takes place by the reduction of primary and secondary natural forest areas. The loss of natural forests is especially serious in the major rubber production areas of Asia, because they are located within the so called Indo-Burma hotspot, one of the 34 global biodiversity hotspots identified by Conservation International (2007). This region largely corresponds with the Lower Mekong catchment area and also includes parts of southern and western Yunnan as well as southern Chinese offshore islands such as Hainan.

The replacement of any type of forest by a rubber monoculture results in a reduction of natural tree species diversity to zero, because the rubber tree is not even native to that region. Many studies also confirm significant reductions of fauna in plantations compared to natural forest. For example, Danielsen and Heegaard (1995) found that conversion of primary forest to rubber and oil palm in Sumatra led to simple, species-poor and less diverse animal communities with fewer specialized species and fewer species of

importance to conservation. In the plantations, only 5-10% of the primary-forest bird species were recorded. Primates, squirrels and tree-shrews disappeared except for one species. Similarly, PEH *et al.* (2005) found reductions in primary-forest species of more than 70% in such habitat types in Malaysia.

There are two approaches to reduce biodiversity losses in rubber and other types of monoculture plantations. The first is the diversification in terms of plant species richness and vegetation structure of the plantation itself, and the other is the preservation of landscape diversity, specifically the maintenance of natural forest patches within plantation areas.

Diversification of rubber plantations is realized in a variety of cropping systems. From southern Yunnan (China), WU *et al.* (2001) classified the existing rubber plantations into four types. These are

(a) monoculture rubber, representing the most common type,

(b) temporarily intercropped rubber plantations, with annual crops (e.g. upland rice, corn pineapple, passionflower) established between young rubber trees before canopy closing,

(c) rubber plantations of multiple species and layers of shrubs and perennial herbaceous plants such as tea, coffee, cardamom and vanilla, and

(d) mixed rubber plantations based on the principles of traditional home garden systems with perennial plants including tea, coffee, fruit trees bamboo and bananas, which are mainly established in aging rubber plantations.

In this sequence, there is an increase in structural as well as plant diversity, but most or all of these plant species do not represent natural forest species. Although no studies on faunal diversity have been conducted in these types of plantations, it can be expected that it is still very low and do not support significant numbers in forest species. In terms of plant species diversity and structure, such polyculture systems are probably similar to the mixed-rural landscapes in Malaysia, consisting of agricultural land, oil palm, rubber and fruit tree stands (PEH *et al.*, 2005).

More complex and more diversified is the so-called "jungle rubber", "rubber garden" or "rubber agroforest" system of Indonesia, specifically Sumatra and Kalimantan. It can be defined as a balanced, diversified system derived from swidden cultivation, in which man-made forests with a high concentration of rubber trees replace fallows. Most of the income comes from rubber, complemented with temporary food and cash crops during the early years (GOUYON *et al.*, 1993). In its structure, they resemble secondary forest with wild species tolerated by the farmer.

BEUKEMA *et al.* (2007) compared plant and bird diversity of the Indonesian jungle rubber agroforestry system to that of primary forest and pure rubber plantations. They found that species richness in jungle rubber was slightly higher (in terrestrial pteridophytes) similar (in birds) or lower (in epiphytes, trees and vascular plants as a whole) than in primary forest. For all groups, species richness in jungle rubber was generally higher than in rubber plantations. The authors conclude that the jungle rubber system does support

species diversity in an impoverished landscape increasingly dominated by monoculture plantations. From a more specific study on terrestrial pteridophytes (ferns and fern allies) in jungle rubber and primary forest, Beukema and van Noordwijk (2004) conclude that jungle rubber systems can play a role in conservation of part of the primary rain forest species, especially in areas where primary forest has already disappeared.

Of economic reasons, however, the most common type of rubber cultivation is the monoculture system. In such landscapes, natural biodiversity can only be conserved in remaining plots of natural vegetation, which should be preserved as reservation areas. Several aspects of this approach needed to be considered for practical implementations (Debinski *et al.*, 2001):

(a) The frequency and spatial distribution of habitat fragments and patches determines species distribution patterns.

(b) Species populations may be separated on patches of their habitat within a landscape of less suitable habitat, and

(c) Species dispersal patterns may interact with patch size and patch context to determine species distributions within and among patches ("patch context" describes the habitat type adjacent to a patch)

Derived from this, a concept for measuring landscape structure has been developed, named "landscape connectivity" (Merriam, 1991). It describes the degree to which the landscape facilitates or impedes movement of species populations among habitat or resource patches. An important question related to this is whether the size and structure of the landscape matrix acts as a corridor or barrier between patches.

All these points also apply to forest patches within monoculture rubber plantations. However, no study dealing with matrix effects on species movements in such landscapes has been conducted so far. Specifically, there is no information on the arthropod diversity of rubber plantations in comparison to forests. In order to develop species conservation concepts in rubber dominated landscapes, research needs to address this question.

5 Ecosystem Services

Ranging from the provision of clean drinking water to the pollination of fruit crops, mankind is deriving benefits from a wide array of processes and interactions that take place in our environment. These services are vital to the functioning of our ecosystems, and vital to the livelihood of men, as they provide not only the basis for human life, but also additional attendances like food and health security or cultural and spiritual values. The total amount of these services can only be estimated, but cautious predictions state a yearly value of 33 trillion (10^{12}) US$ (Costanza *et al.*, 1997; Eamus *et al.*, 2005).

Generally, ecosystem services can be grouped into four categories. (1) Provisioning services that include goods taken from the ecosystem like food, fiber, fuel, genetic resources, fresh water and biochemicals. (2) Regulating services take place on a more global scale; they include climate regulation, pest and disease regulation, natural hazard protection, water purification. (3) Cultural services include recreation and aesthetic

values, knowledge system, spiritual and religious values. (4) Supporting services comprise soil formation and retention, provision of habitat, primary production, water and nutrient cycling (Millennium Ecosystem Assessment, 2005).

Ecosystem goods and services are in danger as the human impact on the environment is constantly increasing (IPCC, 2007). Deforestation and the increase of agricultural areas, water pollution and rising fresh water demand, degradation and unsustainable use have put many ecosystems on the brink of collapse.

6 Impacts of rubber cultivation on ecosystem services

In South-East Asia large areas of natural vegetation with their plentiful diversity of flora and fauna have been put under great pressure from the establishment of plantations. Rubber is playing a great role in this process, as the anticipated revenues are appealing to farmers and policy makers alike. In China's Yunnan province, more than 11% of the total area is covered with rubber (Li *et al.*, 2007), but there are townships where rubber cultivation contributes to more than 45% of the land cover (Hu *et al.*, 2007). For one of these townships, Menglun, Hu *et al.* (2007) estimated the value of ecosystem services provided. According to this report covering land use change over a period of 18 years, the total value of ecosystem services dropped by US$ 11.4 million (28%). The services most affected were nutrient cycling, erosion control and climate regulation. The biodiversity service of "habitat/refugia" had not been covered, but considering the detrimental effect of monoculture plantation systems on species richness and the corresponding ecosystem services, the total value of ecosystem services for the research area can be expected to be even lower than reported.

This effect seems to be alleviated by the fact that the townships gross domestic product increased, leading to a ratio of 1:1.39 for increase in GDP to loss of ecosystem services in US$ (Hu *et al.*, 2007).

7 Deforestation due to rubber expansion

The increasing demand for natural rubber products has lead to a wide spread replacement of natural forest vegetation with rubber. Li *et al.* (2007) states that, between 1976 and 2003, tropical seasonal rain forest in Yunnan was reduced by 67%, mainly due to the planting of rubber. Lowland rain forests are the most affected forest types due to the climatic needs of the rubber tree. But also mountain rainforests and other forest communities of higher elevations are seriously under pressure, as agricultural production shifts into these regions.

According to the recommendations given by the International Panel of Climate Change (Houghton *et al.*, 1997) as used by Germer and Sauerborn (2007), we assessed the potential amounts of carbon and carbon dioxide emission that are expected when preparing land for the conversion into rubber plantations.

Again, the data from the Yunnan Institute of Forest Inventory and Planning Li *et al.* (2008) served as a basis for our biomass assumptions. As basis for the distribution of

below to above ground biomass, we used a BGB to AGB ratio of 1:1.13 as given by the HOUGHTON *et al.* (1997).

For the emission of CO_2 during decomposition, we assume that after 30 years under humid subtropical conditions, all cleared biomass, above and below ground, will be decomposed. HOUGHTON *et al.* (1997) suggests a vegetation independent forest carbon stock estimate of 50% of the biomass. Carbon (12 g/mol) will mostly be released as carbon dioxide (44 g/mol). One ton of cut forest biomass would release 0.5 t of carbon through decomposition, resulting in the emission of 1.8 t CO_2.

As an example, the average carbon content of one hectare of undisturbed tropical seasonal rainforest in Yunnan was reported to be 121.74 t, which is an estimated 243.5 t of biomass, assuming a forest stock carbon content of 50% (HOUGHTON *et al.*, 1997). The complete decomposition of this amount would lead to the emission of (243.5 t $\times$ 1.8) $=$ 438.3 t CO_2.

Table 5: Emission of CO_2 equivalents by forest clearing.

	Carbon content ($t\ ha^{-1}$)	*Above ground biomass* ($t\ ha^{-1}$)	CO_2 *emissions decomp.* ($t\ ha^{-1}$)
TSRF	121.74	212	438
TSRF anth.	75.17	131	271
SEBF	105.24	183	379
SEBF anth.	71	124	256
Grass	5.32	4.4	19.2
Shrub	14.56	25.3	52.4

TSRF: tropical seasonal rainforest; *SEBF*: subtropical evergreen broadleaf forest (57% of Yunnan forests); *TSRF anth.*, *SEBF anth.* both with strong anthropogenic influences (e.g. selective logging); *Grass*: grassland, *Shrub*: shrubland. Carbon content values from LI *et al.* (2008), other values calculated following IPCC guidelines.

8 Carbon sequestration potential of rubber

Properly managed rubber plantations that are supplied with sufficient amounts of fertilizer have a high potential to act as a continuous sink for atmospheric carbon dioxide (CHENG *et al.*, 2007). This is mainly due to their high sequestration rates and the fact that there is a constant export out of the production system by means of tapping.

CHENG *et al.* (2007) reported a 30 years lifetime carbon sequestration of 272 t C ha^{-1} in rubber plantations on the island of Hainan. Comparing this to the sequestration rates of rain forests and secondary forests on Hainan, 234 and 150 t C ha^{-1} over the same period, the high productivity of a rubber plantation becomes discernable. Nevertheless, more than 57% of the sequestrated carbon ends up in easily decomposed litter. This decomposition process returns considerable amounts of carbon back to the atmosphere, up to fifty percent of the total carbon content in the first year (ANDERSON and SWIFT, 1983).

Based on the equation used by CHENG *et al.* (2007), we were able to derive carbon sequestration values for rubber plantations (C_R) in Yunnan province, China's second biggest rubber producer. We can calculate C_R as:

$$C_R = C_{Bi} + C_{La} + C_{Li},$$

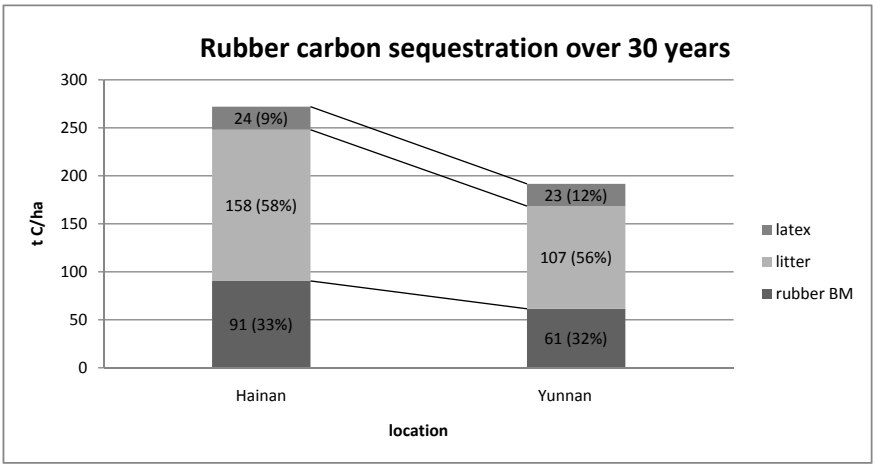
with the carbon content of biomass (C_{Bi}), carbon content of latex yield C_{La}, and the carbon content of litter (C_{Li}).

Data from the Yunnan Institute of Forest Inventory and Planning published by LI *et al.* (2008) were used to obtain information about local forest biomass and its carbon content (C_{Bi} = 61.48 t C ha^{-1} for rubber plantations below 800m).

The amount of sequestrated carbon that is removed from the field during latex tapping was estimated by multiplying average values of latex carbon content by latex yield per hectare (FAOSTAT, 2008) by the economic lifetime of a rubber plantation in years (C_{La}). Due to suboptimal climate conditions rubber tapping in Yunnan usually begins seven years after establishment of the plantation, in comparison to an average of five years reported for Hainan. This results in a slightly lower average economic lifetime. In order to estimate the amount of litter produced over 30 years we proportionally adjusted the values for Hainan litter biomass per hectare to the lower total biomass of Yunnan rubber plantations (C_{Li}).

Based on these calculations, the estimated carbon sequestration during a 30 years lifetime for rubber plantations below 800m elevation in Yunnan province is 192 t C ha^{-1}, which consists of an estimated litter mass of 107 t C ha^{-1} and a latex output of 23 t C ha^{-1}.

Figure 2: Total carbon sequestration by rubber over 30 years per hectare. Total values are divided into latex production, litter production and rubber biomass (non-litter)



These estimates do not consider the soils potential to release and sequestrate carbon under different management regimes. In this context, the dynamics of carbon cycling regarding the substantial amounts of litter produced by rubber plantations should be put to further investigation, as these results could lead to a clearer picture of the overall carbon sequestration potential of rubber.

9 CO_2 balance in plantation establishment

During its lifetime of 30 years, a rubber plantation in Yunnan province can sequester an estimated 192 t of carbon or 703 t CO_2 per hectare (based on an atomic weight ratio of 1:3.66). Plantations in Hainan province can be expected to achieve about 272 t of C sequestration, mostly due to their higher biomass and litter production. These values are, as stated above, comparable to the 30 years sequestration potential of Hainan rainforests.

When comparing these vegetation types concerning their CO_2 balance, one decisive fact has to be considered. Rubber plantations are man-made ecosystems which replace local floral communities entirely. In most cases, this is done by clearing the forest for the plantation establishment.

Based on our estimates, if one hectare of relatively undisturbed tropical seasonal rainforest in Yunnan province is cleared, this process releases about 438 t of CO_2 into the atmosphere. A fully grown rubber plantation on the same spot would need around 20 years to re-sequester this amount of CO_2 . Although after several decades a net gain in carbon fixation could be achieved, the loss in biodiversity and ecosystem resources would be persistent.

Table 6: Carbon sequestration over 30 years and annually

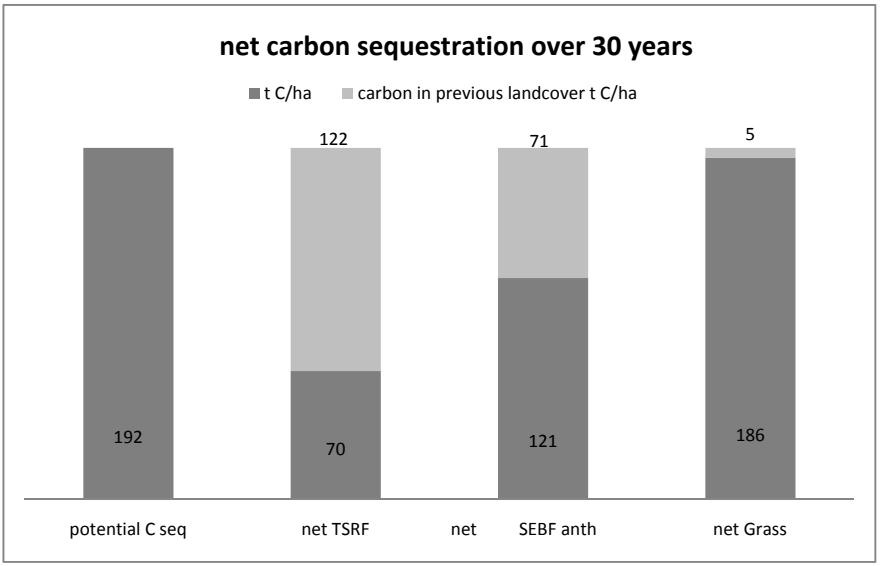
		Rubber	*Rainforest*	*Secondary*
Hainan				
	C_{seq}30 ha^{-1}	272 t	234 t	150 t
	av. C_{seq} a^{-1} ha^{-1}	9.1 t	7.8 t	5.0 t
Yunnan				
	C_{seq}30 ha^{-1}	192 t	165 t est.	106 t est.
	av. C_{seq} a^{-1} ha^{-1}	6.4 t	5.5 t est.	3.3 t est.

Carbon sequestration rates per hectare over 30 years and annual average. Data for Hainan were published by CHENG *et al.* (2007); values for Yunnan Rainforest and Secondary forest were derived proportionally from Hainan sequestration rates and Yunnan biomass values.

10 Rubber and grassland rehabilitation

In order to find more sustainable locations for the establishment of rubber plantations, disturbed ecosystems like degraded grassland and abandoned fallows from swidden agriculture could be used. These land uses are rather scarce in the elevation levels that are suitable for rubber plantation in Yunnan province, but nevertheless it is a promising concept for other regions nearby. All throughout the tropics and subtropics, the transformation of agricultural areas to grassland ecosystems is a common problem. These areas are often dominated by very competitive grass species that effectively prevent natural succession into secondary woodlands and forests. The conversion of these land use types into rubber plantations would not only increase the farmers' welfare but also secure important ecosystem services that grassland and fallows have difficulties to provide (Li *et al.*, 2008). In addition, the establishment of plantations on these degraded areas would emit decisively less carbon dioxide than the conversion of forests. CO_2 release into the atmosphere during land preparation is estimated to amount to about 110 t ha^{-1} for shrubland in Yunnan, and 19 t ha^{-1} for grassland, in comparison to the 438 t ha^{-1} for Yunnan seasonal rainforest. Compared to the values reported above, this would lead to a faster and significantly higher net gain in CO_2 sequestration by rubber plantations when used to rehabilitate grassland. Similar results have been published for oil palm plantations (Germer and Sauerborn, 2007).

Figure 3: Carbon sequestration by rubber grown below 800 masl. over a period of 30 years in Yunnan province, compared to net carbon sequestration considering the release of CO_2 during plantation establishment. C seq. is the estimated carbon sequestration potential of rubber (above); previous land cover: TSRF is tropical seasonal rainforest, SEBF anth is subtropical evergreen broadleaf forest with anthropogenic influence and Grass is grassland.



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Caught between Energy Demands and Food Needs: Dilemmas of Smallholder Farmers in Njoro, Kenya

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Abstract
Smallholders in rural Kenya, like their counterparts in tropical Africa currently face acute shortage of fuel wood for domestic use. There has been rapid population increase in the last few decades resulting in increased demand for food crops. This has led to the expansion of area under subsistence agriculture eating into indigenous forests, the traditional source of wood fuel. This situation has been compounded by the limited access to alternative sources of domestic energy in rural parts of Kenya. The recent upsurge in the cost of fossil-derived fuels as well as in hydro-generated electricity has left the smallholder farmer with wood as the sole source of fuel. This paper therefore examines the conflicting demands of domestic fuel needs and foods. Key research questions were: What are the household domestic energy demand and constraints? What is the household food demand and constraint among smallholders? How do the smallholders reconcile these competing basic needs? The paper reflects on the constraints of smallholders in their quest to fulfill their food and energy needs. The discussed model is a result based on discussions between the researchers and focus group discussions drawn from smallholder farmers. The primary data gathered from the discussions is augmented by secondary data to draw imperative implications on domestic energy use and food needs. The results indicate an average annual per capita wood fuel demand of 1.99 m^3 and a deficit of 8.816 m^3 per household. The deficit is usually catered for through purchase of wood fuel from the market, which has an implication on the pressure exerted on the forestry resources. This paper shows that households in Njoro have turned to desperate coping mechanisms and strategies such as use of maize straw, pruning and fallen twigs. The results of this study provide insights on how the dilemma may be resolved in a smallholder setup and suggest local policy options.

Keywords: woodfuel, smallholder farmers, food demand, Kenya

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1 Introduction

About half of the world's population use fuels from biomass as an energy source in households: for cooking, lighting and heating (Brouwer *et al.*, 1997; Mahiri, 1998). The energy sources are fuel wood, agricultural residues (for example maize cobs or maize straw), charcoal or dry cow dung. In most African rural and low class urban households, wood fuel continues to be a major source of cooking fuel and plays a vital part in energy supplies of many developing countries (e.g., Mahiri and Howorth (2001); Okello *et al.* (2001). Many households in the rural areas depend entirely on this type of fuel whereas their counterparts in low class urban areas frequently use it in combination with other forms of energy such as paraffin and electricity. In Kenya, it is estimated that wood provides about 73 per cent of total energy consumption, mainly as fuel wood for cooking and heating in rural areas, and as charcoal in urban areas (Government of Kenya, 1997). The current annual supply of woodfuel is estimated to be 18.7 million tonnes. The trend of consumption of fuel wood in Kenya has been shown to vary with ecological zones (Kituyi *et al.*, 2001).

In the 1970s the "woodfuel gap theory" was first brought to the world's attention. This implied that woodfuel was being consumed on an unsustainable basis (Bradley and Campbell, 1998; Mahiri and Howorth, 2001). The "gap" indicated that woodfuel demand was larger than the sustainable supply, defined as the mean annual increment of wood biomass (FAO, 1983). It was then concluded that deforestation and forest degradation were largely due to firewood harvesting (IUCN, 1996). With mounting concerns for the woodfuel sector, national and international agencies commenced many research programs on the relationships between woodfuel supply and demand. For example in Kenya, the Kenya Woodfuel Development Programme (KWDP) developed a three-tier approach to the study of rural woodfuel energy supplies (Bradley, 1988). It involved three highly densely populated districts (Kakamega, Kisii and Murang'a) between 1983 and 1986. Some of the more important conclusions which emerged from this work include the following: (a) The integration of tree production into general farming activities is complex and deeply-rooted. Local farmers have an intimate knowledge of the benefits and weaknesses of the different trees growing in different situations on the farms. These are manifest in different ways among the sub-regions of the districts. (b) As a proportion of the total on-farm woody biomass, deliberately managed and planted woody biomass increases with increasing population density. (c) Contrary to expectations, as population density increases and farm size diminishes, the amount of land devoted to woody biomass production increases. In the southern third of Kakamega District, with rural population densities exceeding 700 per km^2, more than 20% of the land is devoted to woody biomass. (d) It was estimated that 31% of the district's farms experience a shortage of greater than 50% of needs. Only 21% have a surplus. Despite such a high proportion of land devoted to trees, the population densities are so high that these areas experience the greatest deficits.

Smallholders in rural Kenya, like their counterparts in tropical Africa currently face acute shortage of fuel wood for domestic use. There has been rapid population increase in the last few decades resulting in increased demand for food crops. This has led to

the expansion of area under subsistence agriculture eating into indigenous forests, the traditional source of wood fuel. However, the rural household energy problem cannot be treated in isolation from the equally pressing issues of food, poverty, labour, culture and values (Mahiri and Howorth, 2001). This study aimed to assess the energy and food demand nexus and the coping strategies. Given that fuel wood production competes with food production for land, there is need to understand household dilemmas in meeting woodfuel and food needs and strategies of resolving the conflict.

2 Methodology

The main data for the study include woodfuel production, food production, socio-economic characteristics as well as perceptions on woodfuel and food availability. This study utilized focus group discussion as the main data collection method in two rural villages in Nakuru district, Kenya. Verifications were done through actual measurements of the firewood bales in Njoro market to estimate the volumes. Data was analyzed using descriptive methods which entail computation of averages, calculation of frequencies and estimation of food and fuel demands.

3 Results and Discussions

3.1 Household socioeconomic characteristics

Household socioeconomic characteristics The interviewees were mainly small scale farmers, 80% being women. Average land ownership was 1.38 ha, used mainly for subsistence food crop production (71.37%), pastures/ fodder crops (25.0%) and settlement (about 3.62%). The average household size was 6 persons which was slightly higher than the national average and the mean age of respondents was 45 years. Their main economic activities were farming and small scale businesses.

3.2 Household food and fuel demands: Household Dilemmas

The main source of fuel used among the households is firewood, with a few using charcoal occasionally and gas, rarely. Those who had used gas before said that they are no longer using it because of higher prices for petroleum products. Currently liquidified gas; retail at Kshs. 135.56 (1.38 Euros) per kilogram. Another frequently used fuel mainly for lighting is paraffin, with costs of about Kshs. 100 (1 Euro) a liter.

Firewood, the major fuel source for the households in the study area was usually acquired from own farm or purchased from hawkers, who transport it using bicycles from Mau forest, which is 20 to 50 kilometers away. A firewood bale[1] of about 0.17 m^3 costs Ksh. 500 (5 Euros), on the market. For a household consisting 6 members on average, which was the mean number of members per household in the study area, the annual firewood demand is 11.96 m^3 per household. Out of this, only 3.144 m^3 (26.28%) is acquired from within the farm as tree pruning or fallings, and the rest (11.95 m^3) from the market. Consequently the annual per capita wood fuel demand translates to about

[1] This is the volume of wood after provisions for air spaces, which constitute about 40% of the measured bale.

1.99 m^3. These results indicate a large deficit of wood fuel (Table 1), which is usually satisfied through clearing of indigenous and artificial forests, threatening biodiversity.

Table 1: Household supply and demand of firewood in Ogilgei, Njoro

Period	*Supply from own farm (m^3)*	*Demand (m^3)*	*Deficit (m^3)*
Monthly	0.262	0.68	0.418
Annually	3.144	11.95	8.816

Source: Authors' computation from field interviews.

The annual demand for maize per capita in the area was 118 kg, hence a family of 6 members requires 708 kg annually. Given an average yield of 1900 kg per hectare (Bett *et al.*, 2008), the household needs 0.37 ha to be food self sufficient. Given the average land allocated to food production, there is an indication that the households are producing surplus food for the market, using the income to cater for basic household needs including purchase of fuel wood. Woodfuel expenditure takes a substantial proportion of household budget. Although there is an opportunity for households to increase their own farm fuel wood production through planting of more trees, such approach would reduce the land under food crop production. Given the above scenario, the consequences of the pressure exerted on forestry resources by both food and wood fuel demands are far-reaching. Unless campaigns strengthening farm forestry strategies and other environmentally friendly strategies like agro-forestry are intensified, the crisis will get worse. This situation will further be exasperated by the current global fuel and food crisis. Poor farmers will have a higher burden, since they have to allocate their meager resources to food and fuel purchase, leaving very little if any for other basic needs. This is made worse by the fact that the area has witnessed rapid land use and land cover changes in past decade, involving vast clearance of indigenous forests to create farm land the farmers used to depend on as a source of firewood. These changes have created a food and fuel crisis in the area, forcing rural smallholder farmers in the area into a great crisis, threatening their livelihoods. In addition, food production is constrained by declining soil fertility, high fertilizer prices, erratic weather conditions and this worsens the wood fuel-food production crisis.

3.3 Survival strategies

Results ascertain the supposition that there has been a rapid decline in the mostly used wood fuels in the area: charcoal and firewood. The farmers in the discussion said that the last decade has been the worst in terms of the trends of declining wood fuel. Some of the coping strategies used by the rural poor include, purchasing of wood fuel from the market (something they never used to do before), use of alternative fuel such as small fallen twigs and maize stalks. Most of the farmers sell surplus food produce and use some of the money to purchase woodfuel. However, the strategy is not sustainable due

to erratic climatic conditions and poor, eroded soils that result in low crop yields. Other respondents indicated that they even use the fencing poles, which had been erected during the days when there were no shortages of wood products. Among the farmers, there was none with a woodlot, but the majority had trees scattered on their farms and along boundaries. The farmers cited land size as a major reason why they do not plant trees since food production is given priority. Another constraint reported was frequent rain failure, leading to very low survival rates of trees. Watering of trees cannot be sustainable in the area, since they have to buy water for household use and livestock consumption at the rate of Shs. 3 (0.03 Euro) per 20 liter container. Furthermore, even where farmers have made efforts to grow trees in order to address the problem, the growth rate of trees is too low to match the rate consumption. The average number of mature trees was 35, giving an average density of 25 trees per hectare. This density is too low considering the annual wood fuel demand.

4 Conclusions and policy Implications

The study reveals that farmers face a dilemma in allocating land for food and wood fuel production. Due to a high deficit in on-farm wood fuel production at household level; farmers resort to the market. Most of the marketed fuel wood is illegally obtained from government forests. In the long run this may not be sustainable and due to strict government control on access to forest fuel wood, the supply from this source has declined, leading to escalating fuel wood prices.

Towards mitigating these effects, the study draws imperative implications providing insights on how the dilemma may be resolved in a smallholder setup. We follow an integrated energy concept, which includes different alternative energy systems and sources, and energy efficient techniques.

First, there is need to promote *alternative sources* of energy such biogas and solar energy. Biogas is a promising alternative since most households rear livestock especially cattle. The potential for solar energy is high given that the area is located in a tropical area with about 10 hours of sunshine per day all year round. Second, *promotion of agro-forestry* is necessary. Efforts can be targeted towards promotion of fast growing agro - forestry and hedge / boundaries tree species so as to match wood fuel consumption. Also so called energy plants integrated into agro-forestry systems could be a solution. Third, farmers need to use *energy saving firewood stoves*. This is necessary in order to reduce fuel wood consumption.

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Jatropha curcas L.: Visions and Realities

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Abstract
Since several years Jatropha is experiencing a renaissance. The main drivers for this development are the biofuel boom in general and the special attributes of Jatropha itself. This paper discusses the current knowledge as well as expectations of Jatropha and the consequential outcomes starting with data availability and quality followed by economic and political needs and constraints. Text

Keywords: Jatropha curcas, biofuel

1 General Data about Jatropha

From the genus Jatropha known to date with about 165-175 species (Heller, 1992) *Jatropha curcas* L. (*J. curcas* L.) is seen as the most primitive species within this group. Heller states that the provenance of *J. curcas* L. can be located in South America. However, a different position is presented by Münch and Kiefer (1986) which argue that *J. curcas* L. could have its origin already in Gondwanaland and, therefore, can be found in America, Africa and probably Asia as well. Another hypothesis shared by most authors is that *J. curcas* L. was spread by Portuguese seafarers to Africa and India. To date, a final scientific clarification of the spread of *J. curcas* L. is pending.

A rough picture of the area theoretically suitable to *J. curcas* L. cultivation, was presented by Jongschaap *et al.* (2007). The authors claim that "the most suitable climate conditions for the growth of Jatropha (*J. curcas* L.)" can be expected between 30°N and 35°S. This theoretical widespread distribution is restricted to zones with no frost, sufficient water availability, and soil conditions supporting Jatropha plant growth.

The promoters of Jatropha production for renewable energy production claim that:

- it can be grown on marginal soils
- it is drought resistant
- it requires no high soil fertility
- it is to a certain point pest resistant
- it provides even under this restrictions high yields

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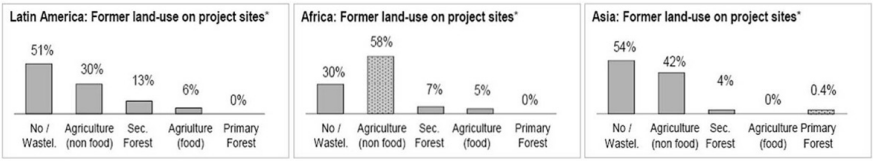
This leads to the argument that Jatropha plantations will not compete with food production when compared to Palm oil or Sugar cane production. However the case is not as simple as stated.

Marginal land is classified by the OECD as "land of poor quality with regard to agricultural use and unsuitable for housing and other uses" (OECD, 2001).
However, this definition regarding the possible locations for cropping Jatropha does neither include physical and chemical soil terms nor climatic conditions which can influence the growth response of Jatropha. Although Münch and Kiefer (1986) state that Jatropha is adaptable to most soil conditions, their interdependencies are not explored yet. A first overview of different land types allocated to current Jatropha plantations (Figure 1) is shown by a study of the organisation "Global Exchange for Social Investment" (GEXSI) in 2008.

Figure 1: Land Use for Jatropha.



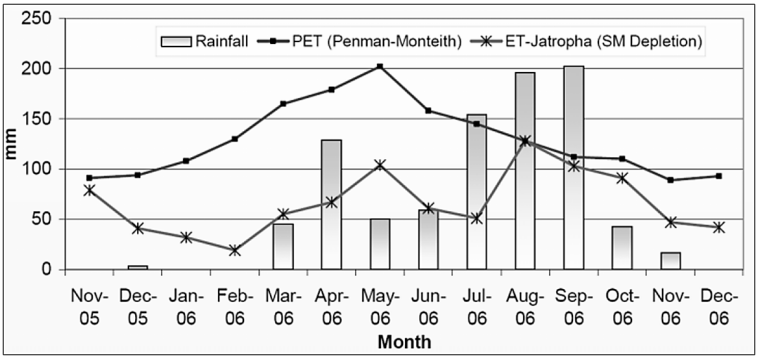
Source: GEXSI (2008), * Sample n = 90 projects with a total planted acreage of 325,000 ha

Münch and Kiefer (1986) pointed out that Jatropha can survive with an annual rainfall of 400 mm. However, Francis *et al.* (2005) state that for production purposes 900 – 1,200 mm rainfall or water supply are needed. Not only the total amount of annual rainfall but also the distribution of water supply within the year (Figure 2) is important for plant growth as was shown by Wani *et al.* (2007).

Nutrient demand of Jatropha is mostly calculated based on the nutrient content of the Jatropha seedcake exported from the site of production, assuming that only the Jatropha seeds leave the production system. This view is supported by Münch and Kiefer (1986) who state that the pressed oil contains theoretical only water and CO_2, and, therefore, no nutrients will be extracted other than those contained in the Jatropha seedcake. Results of seedcake nutrient analyses presented by different authors are shown in Table 1. A broader nutrient analysis of the all Jatropha components was presented by Jongschaap *et al.* (2007). Based on mean values from Table 1, for a harvest of 1000kg of Jatropha seeds, on average[1] 40 kg Nitrogen, 16 kg Phosphorus, and 10 kg Potassium need to be added to the plantation, to at least balance the macro nutrient outtake and to maintain soil fertility.

[1] Assuming 25 % of weight is extracted Jatropha oil and 75 % of weight is seedcake

Figure 2: Water relations for the growth of a 2 years old *J. curcas* plantation at ICRISAT (India) from November 2005 to December 2006. ET = Evapotranspiration; PET = Potential evapotranspiration; SM = soil moisture.



Source: Wani *et al.* (2007), cited in Jongschaap *et al.* (2007)

Table 1: Nutrient composition of Jatropha seed cake as recently presented by different authors.

Nutrient	Wani *et al.* (2007)	Francis *et al.* (2005)	GTZ 1995	Sreedevi (2005)
Nitrogen (%)	4.91	5.7-6.5	5.72-6.48	4.44
Phosphorus (%)	0.90	2.6-3.0	2.61-3.06	2.09
Potassium (%)	1.75	0.9-1.0	0.90-0.97	1.68
Calcium (%)	0.31	0.6-0.7	0.60-0.66	
Magnesium (%)	0.68	1.3-1.4	1.26-1.34	
Zinc (ppm)	55			
Iron (ppm)	772			
Copper (ppm)	22			
Manganese (ppm)	85			
Boron (ppm)	20			
Sulphur (ppm)	2433			

The assumption that Jatropha is relatively resistant to pests and diseases might strongly rely on the fact that current knowledge is generally based on experimental plots or small scale experience. Growing Jatropha in large scale monocultures will increase the risk for pests and diseases to occur. A group of organisms likely to affect Jatropha, such as fungi (e.g. phytophtora, mucoraceae), insects (e.g. stem borer, leaf miner, caterpillars, and scale) and diseases (e.g. mosaic virus) was defined by Grimm (1999); Münch and Kiefer (1986); Narayana *et al.* (2006); Shanker and Dhyani (2006); Tewari *et al.* (2007); Üllenberg (2008). To which extend they will affect individual plants

or need to be treated in larger scale plantations is not known to date. Especially the possible interaction between the Jatropha mosaic virus and the cassava mosaic virus needs to be studied in more detail. Evene remote possibilities for the virus to spread from one culture to the other, requires safeguard measurements to be taken as cassava serves as staple food in many developing countries.

Breeding of Jatropha is yet in its early stages as Jatropha still is classified as a wild, non-domesticated species. This is clearly shown by the high variation in seed morphology and oil content. KAUSHIK *et al.* (2007) found for 24 accessions[2] that the hundred-seed weight ranged from 49.2 g up to 69.2 g and the seed oil content varied from 28% up to 38.8%. However, the authors state that "in general the phenotypic coefficient of variation was higher than the genotypic coefficient of variation indicating the predominant role of the environment". Nevertheless, current results of worldwide Jatropha screening constitute the first step towards promoting breeding success. In the case of India, KAUSHIK (2007) aims to develop a stable variety of Jatropha with at least 35% seed oil content and seed yield of 2 kg per plant and year within the next 8 years.

This uncertainty raises the question if the assumption of Jatropha providing high yields under sub-optimal and marginal conditions is supported by the current knowledge base (JONGSCHAAP *et al.*, 2007).

2 Agronomic Data of Jatropha

Research on Jatropha has started more than 20 years ago. Unfortunately, this research was characterized more by sporadic action than by continuous work. This explains the current lack of in-depth and long term information on *J. curcas* L. production systems, leading to the fact that current plantation practice is mainly based on data from experimental plots and small scale experience. Therefore, all *J. curcas* L. growers are forced to make decisions according to the local conditions where he wants to establish a *J. curcas* L. plantation.

Suggestions available as to how to establish and manage Jatropha plantations range from spacing of 2.5m $\times$ 2.5m to 4m $\times$ 4m or even wider spacing, different planting hole depths, different application doses of start up fertilizer, and the choice of using either cuttings, seedlings or direct seeding. A study carried out by GEXSI (2008) provided a first overview on *J. curcas* L. projects on a global scale. Their results[3] show that according to the different planting techniques nurseries were used in 85%, direct seeding in 45%, cuttings in 40% of the projects, and in about 20% of the projects even two or all three methods were used simultaneously. Since planting shortly before a rainy season will provide the needed water supply for enhanced plant growth, the local climatic and soil conditions need to be carefully considered. Pruning of Jatropha in the first years leads to a more bushy structure supporting a higher flowering rate and thus increasing yields. Within the sample of 90 projects 80% used pruning, 67% used fertilizer and 49% irrigated their plantations (GEXSI, 2008).

[2] *Jatropha curcas* collected from different agro climatic zones of Haryana state (India)

[3] GEXSI, 2008 "Sample: n = 95 projects"

Assumptions on attainable yields vary widely e.g. for seeds 0.5 to 12 $t\,ha^{-1}\,a^{-1}$ – depending on soil, nutrient and rainfall conditions FRANCIS *et al.* (2005), and for fruits 7.5 $t\,ha^{-1}\,a^{-1}$ (OPENSHAW, 2000). Both authors do not clearly explain the scientific basis supporting these estimates. In contrast, KASHYAP (2007) states for India, that under rainfed conditions, yield is limited to max. 1.5 $t\,ha^{-1}\,a^{-1}$.

The productive lifespan of a Jatropha plantation is yet another uncertainty. There is a significant difference between a plantation being productive for just 30 years (FRANCIS *et al.*, 2005) or up to 50 years (HENNING, 1997).

Variations can be found as well in the figures regarding the efficiency of manual harvesting techniques. VAN EIJCK (2006) estimates that 2 kg of Jatropha seeds can be harvested by one person per hour, Heller (1996) , however, states that 18 kg of Jatropha seeds can be harvested per person per hour. Even figures of up to 50kg per person/hour circulate, but are without scientific evidence. The same situation can be observed for labour data for plantation establishment and maintenance (Table 2).

Table 2: Assumed labour demand to establish and maintain 1 ha Jatropha in man days.

	1st year	*2nd year*	*3rd year onwards*
FRANCIS *et al.* (2005)	200	50	50
BECKER (2008)	91	46	40
KASHYAP (2007)	75 - 80		
WANI (2008)	165	115	110

The inconsistency of the available data does not support decision making processes and invites miscalculations for Jatropha plantation planning, establishment and maintenance, increasing risk of failure should economic viability calculations turn out to be too optimistic.

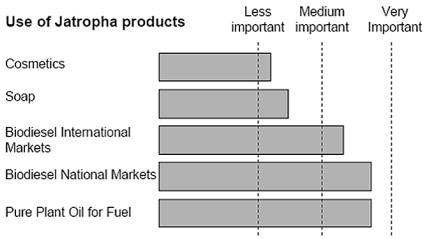
3 Product Range of Jatropha and Possible further Development

Even if the current boom for Jatropha production is based mainly on the incentive of producing biofuel (Figure 3) the possible range of products which can derived from Jatropha is much broader (Figure 4).

The current focus on biofuel as major marketable product from Jatropha has the disadvantage that the economic viability of Jatropha production depends on its strength to compete with fossil diesel and thus relies on the development of crude oil prices. A possible strategy to mitigate the risk of volatile crude oil prices would and should be the development of a broader range of Jatropha based products as stated by MÜNCH and KIEFER (1986). These products could tip the scales of economic viability of Jatropha production even when facing the lack of agronomic data and other uncertainties.

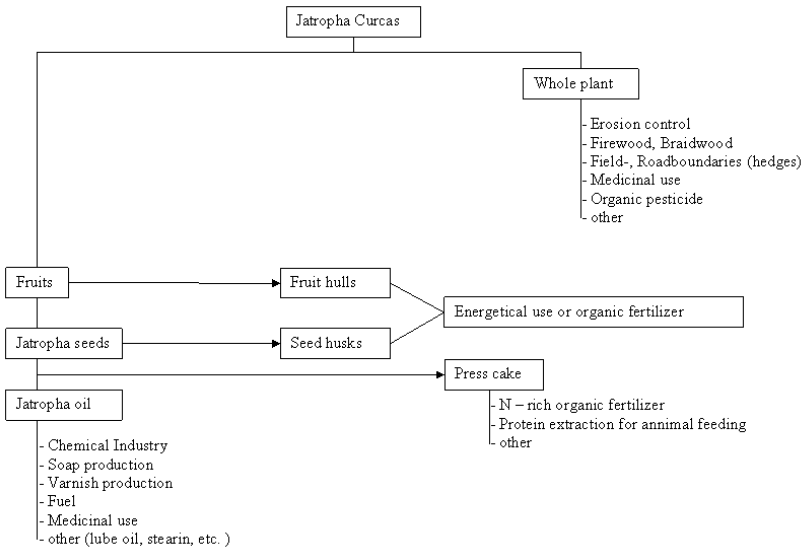
A strategy to develop a more diverse and sustainable market for Jatropha products was proposed by Ranaivoarison (undated) in Madagascar. A step by step approach is considered to make the rural population sensitive to possible income generation via

Figure 3: Use of Jatropha products



Source: GEXSI (2008) based on expert estimates for 39 countries

Figure 4: Range of possible Jatropha based products

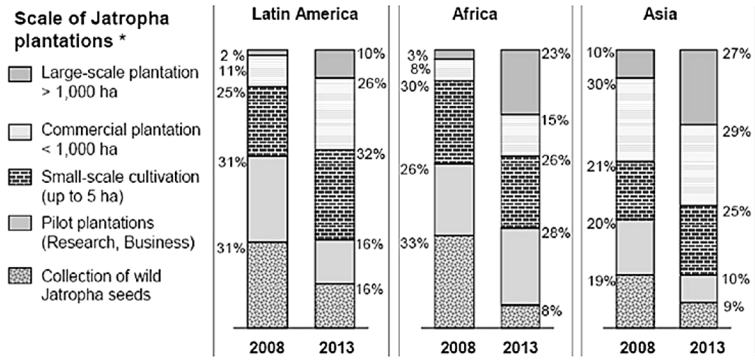


Source: Adapted from MÜNCH and KIEFER (1986)

participation in the Jatropha production. This includes as a first step the establishment of a local market for Jatropha products such as soap or Jatropha oil for lighting purpose, followed by a second step for energy (decentralised electrification) and biofuel production on a larger scale when economic success was proven. An example of Jatropha soap production already entering a local market is that of Kakute Ltd. in Tanzania.

The Jatropha product industry is very young. Few projects are more than two years old and hardly any project can demonstrate significant production of Jatropha oil yet (GEXSI, 2008). However, it is expected that in the near future commercial and large-scale plantations will strongly expand their activities (Figure 5). This increase will lead to an estimated annual global investment of up to 1 billion USD (GEXSI, 2008) per year within the next 5-7 years. Nevertheless, smallholder production seems to play an important role in Jatropha production and is likely to continue to do so.

Figure 5: Possible development of Jatropha expansion



Source: GEXSI (2008), * Information from n = 33 countries with strong or starting Jatropha activities, Expert Country Estimates

4 Political Framework Situation and Future Needs

Many developing countries simply adopt the EU and U.S. measures such as mandatory fuel-blending obligations as well as a broad range of programs to support their national biofuel industries. Beside this, national legislations regulating the growing biofuel sector are still under development or often just starting. Therefore, investors often act in a grey zone that will most probably be subject to rules and regulations in the near future which then could affect their business directly.

One probable outcome is the assimilation of the biofuel sector into the national fossil fuel sector. The main question here will be to which extend policies targeting financial regulations such as taxation or subsidies will be applied to biofuels as they are widely applied to fossil fuels by most developed and developing countries (Bacon and Kojima, 2006; GTZ, 2007).

Another topic for future actions of governments in developing countries are regulations on land ownership and use as currently land property and land title systems are often strongly disputed due to non-existent or unclear legal instruments. Especially land that is classified as common property (often state owned land as well) often provides the basis for the livelihood of the rural poor and thus constitutes an area for future conflicts.

Therefore, investors applying to governments for land to install their production would benefit from a direct communication with the local population and field visits to potential production sites would be a first step to avoid possible conflicts. However, as the number of players in this sector is expanding the competition for land among them and locals is likely to increase.

Mainly biofuel exports targeting EU and U.S. markets will face the sustainable biofuel production standards and certification. Therefore, regulations targeting issues such as environmental protection, energy efficiency, greenhouse gas balance, and social responsibility will play an important role for biofuel production in the near future.

Irrespective of the enthusiasm for biofuel production, possible effects on food production and thus food security need to be carefully observed. Up to now the GEXSI (2008) study revealed that in their sample only 1.2% of areas planted with Jatropha had been used for food production in the 5 years prior to the start of the project. In addition, intercropping is widely used and, therefore, Jatropha production could enhance food production and develop underexploited areas. Nevertheless, the issue needs to be introduced into national policy and regulations to make sure that food security is not compromised.

Among all these uncertainties, the question of social justice has not yet been addressed. Will the local, rural labor force benefit from the Jatropha hype in the sense that a share of potential wealth will reach them or their families, or will they have to stay poor in order to limit production costs and make the system work?

5 Conclusion

There is an urgent need to understand more about Jatropha in general, its possible application and its performance in larger plantations. In addition, breeding programs and selection tools need to be developed to provide appropriate plant material for different agro-ecosystems. This requires an interdisciplinary approach covering Jatropha systems and their determining and limiting factors.

But not only the production system and the plant itself need investigation. Research also needs to focus on the potential range of marketable products based on Jatropha other than biofuel. This includes the development of products, establishment of markets, and definition of framework conditions.

The first steps of coordinated research have been taken and platforms promoting knowledge exchange are already online (e.g. www.jatropha-platform.org, www.jatropha.wur.nl, www.jatropha.uni-hohenheim.de). These actions will provide investors as well as governments and other stakeholders with reliable information to overcome the current challenges. Nevertheless, governments in developing countries will need international cooperation to develop appropriate framework conditions such as national land title systems and should be involved in creating international standards and certifications for biofuels to adapt them to their specific needs.

In conclusion, I strongly believe that the propagation of Jatropha can be seen as a possible option for rural development. Especially if focused on the local value chains with the value generated staying in the region, but as well if income generation from working in a Jatropha plantation provides a positive effect on the livelihood of the rural population.

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The Role of Bio-productivity on Bio-energy Yields

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Abstract
The principal photosynthetic pathways convert solar energy differently depending on the environmental conditions and the plant morphotype. Partitioning of energy storage within crops will vary according to environmental and seasonal conditions as well. Highest energy concentration is found in terpens like latex and, to a lesser extent, in lipids. Ideally, we want plant ingredients with high energy content easily amenable to ready-to-use bio-fuel. Generally, these crops are adapted to drier areas and tend to save on eco-volume space. Competition with food crops could be avoided by fetching energy from cheap agricultural by-products or waste products such as bagasse in the sugar cane. This would in fact mean that reducing power of agricultural residues should be extracted from the biomass through non-photosynthetic processes like animal ingestion or industrial bio-fermentation. Conversion and transformation efficiencies in the production chain are illustrated for some relevant crops in the light of the maximum power theorem.

Keywords: photosynthesis, bio-productivity, bio-energy, energy concentration path

1 Photosynthesis Types

In general, photosynthesis may be considered as the process that stores light energy of the sun into carbohydrates by assimilating CO_2 and H_2O. Mineral nutrients are also required for the functioning of the photosynthetic system.

The transpiration ratio, which is the amount of water transpired per kg dry weight produced, is largest in C_3 plants, about one third in C_4 plants and remarkably low in CAM plants. The light response is saturated at half of full sunlight in C_3 plants, not saturated at full sunlight in C_4 plants and saturated already at one fourth of full sunlight in CAM plants. These special characters result in environmental preferences. C_3 plants dominate in temperate climate, but also occur in the tropics, while C_4 plants are typical of the tropics and subtropics. CAM plants, by contrast, are especially frequent in the arid tropical to Mediterranean climate. Thus, CAM plants are specifially adapted to

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a dry environment. However, the water deficit also limits the maximum growth rate, which ranges between 15 and 20 g per day. The maximum growth rate is maximal for C_4 plants and medium for C_3 plants.

Apart from water consumption, which is a cost-effective factor in agriculture, it is also worth focusing onto the nitrogen use efficiency, because nitrogen fertilization is also cost-effective.

In general, C_3 plants invest about 50% of their total soluble cell protein into Rubisco, because the affinity of this enzyme to CO_2 is low. C_4 plants with their CO_2 concentrating mechanism invest less nitrogen, which is 15% of their total soluble cell protein, into Rubisco. Nevertheless, we have to add another 7% of protein invested into the enzymes typical of the C_4 metabolism. Still, the resulting amount of nitrogen invested into the photosynthetic system is less in C_4 than in C_3 plants. To summarize, C_4 plants utilize significantly less protein for their photosynthetic system, resulting in a higher nitrogen use efficiency.

Table 1: Important physiological differences between C_3-, and C_4-plants. Source: El Bassam (1996)

Component	C_3*-plants*	C_4*-plants*
Apparent photosynthesis (mg CO_2 dm^{-2} h^{-1})	up to 30	60 – 100
Light saturation (W m^{-2})	up to 300	400 - 600
CO_2 compensation point (μl CO_2 l-1)	30 – 90; temp.-sensitive	up to 10; temperature-insensitive
Photorespiration	detectable	not detectable
Optimum of temperature (°C)	10 - 25	30 – 45
Transpiration loss (mole H_2O/mole CO_2)	900 - 1200	400 - 500
Daily growth rate of plants (g/m^2)	34 - 39	50 - 54
Response to CO_2 increase	yes	no
Solar conversion efficiency	0.1 – 0.7 %	1.5 - 2.5 %

2 Energy Concentration of Plant Components

A very high energy content is stored in lipids, 38.9 kJ per gram. Non-surprisingly, lignin is also characterised by a very high energy content 26.4 kJ per gram. The energy content of proteins is not significantly lower. By contrast, the energy content of carbohydrates such as organic acids and sugars is distinctly less, about 15 kJ per gram. An exception may be the group of terpens.

Based on these data, energy plants should store energy preferably in terpens, lipids and lignin. Considering the costs related to the supply of nitrogen by fertilizers, it seems, however, ineffective to use protein crops like soybean as energy suppliers.

Terpenes are derived from the union of 5-carbon isoprene units and they are classified by the number of units.

- Monoterpenes, containing 2 isoprene units, are components of volatile essences and essential oils.
- Sesquiterpenes with 3 units are components of essential oils and phytoalexins.
- Diterpenes with 4 units represent, for example, gibberellins, resin acids, and phytol, which is the side chain of chlorophyll.
- Triterpenes with 6 units are phytosterols and brassinosteroids.
- The best known representatives of tetraterpenes with 8 isoprene units are carotenoids, while
- Polyterpenes form so-called rubber polymers.

Well-known examples of monoterpenes are pinenes, found, for example, in turpentine, limonene, also known as the smell of citrus, and eucalyptol, the smell of Eucalyptus.

With respect to energy plants, rubber-like polymers are of greatest interest, so-called polyisoprenes. Examples are:

Hevea brasiliensis. This rain forest tree is native to the Amazon Basin. It is the main source of natural rubber, called caoutchouc. About 90% of all natural rubber comes from the latex sap of this species.

Palaquium gutta. Known for its gutta-percha. It is a tropical tree, native to southeast Asia and northern Australia.

Achras sapota, also known as naseberry or sapodilla tree. It produces chicle, another polyterpene. This tree occurs in Central America and the West Indies.

Mimusops balata. Like Achras sapota, this West Indies species produces a rubber-like polymer, which differs from caoutchouc in being harder and more viscous.

Parthenium argentatum, called 'why-YOU-lee'. It is a native shrub of Mexico and the southwestern United States. It contains a latex sap with polyterpenes similar to those found in Hevea rubber. It is a potentially good source of natural rubber, possibly grown on large plantations in arid desert regions. Thus, this species is a very interesting alternative, because is can be grown on areas, which are otherwise almost unsuitable for agriculture.

Euphorbia tirucalli. The so-called Pencil Euphorb grows well under semi-arid conditions even on marginal soils, and is widely found in Africa and in North-East Brazil. Preliminary trials were organized in Kenya with this crop by compressing biomass into briquette as a fuel wood for kitchen use in urban areas. *E. tirucalli* combines high drought and salinity tolerance with low-input requirements.

Table 2: Biosynthesis costs (in g glucose)
Sources: Penning de Vries *et al.* (1989); Larcher (1994)

Component	*Energy content (kJ / g)*	*g glucose / g product*	*Transport g glucose / g product*	*Minimum energy costs (kJ / g product)*
Lipid	38.9	3.030	0.159	49.4
Lignin	26.4	2.119	0.112	34.6
Protein	23.0	1.824	0.096	29.8
Glycine (AA)	8.7	-	-	-
Organic acids	-	0.906	0.048	14.8
Oxalic acid	2.9	-	-	-
Malic acid	10.0	-	-	-
Pyruvic acid	13.2	-	-	-
Further Carbohydrates	-	1.211	0.064	19.8
Terpens	46.9	-	-	-
Polyglucan	17.6	-	-	-
Glucose	15.5	-	-	-

AA: Amino acid; 1 Kcal = 4.186 KJ

3 Bio-Productivity of Selected Crops

From a practical point of view, either the entire plant should be used for the generation of energy (e.g., willow) or the harvested portion of the plant should be small in volume and, as a consequence, should contain a high concentration of 'energy' per volume. Examples for this latter strategy are nuts and seeds. A promising alternative may represent the strategy of generating energy by fetching energy from cheap agricultural by-products or waste products from whatever crop.

It is necessary to keep in mind that growing energy plants also requires investing energy. This energy input is the sum of energy required for seed material, nutrient supply, pesticide application, harvest, drying processes, fuel, electricity, buildings, and so on. Yet so-called Output / Input ratios can be calculated, which are the relationship of the energy yield of the main yield component divided by the energy input.

Table 3 offers an overview of the production efficiency rates of selected crops. The Output / Input ratio should, of course, be larger than 1. From a practical point of view, ratios smaller than 2 are not really attractive, which would exclude species such as Pecan, Almond, Grape wine, Sugar beet, Banana, and Apricot from our considerations. Species like Sugar cane, Sorghum, Rice, Rapeseed, Barley, Corn and Wheat, on the other hand, seem comparatively attractive.

Of course, the Output / Input ratio depends on several factors. For example, the Output / Input ratio of corn varies between 0.8 and 128 (Table 4). The latter unusually high ratio resulted from an enormous labour input by hand; however the resulting energy output per labour hour was very small. An excellent balance between the Output / Input ratio and the energy output per labour hour was achieved for corn grown in Illinois.

Table 3: Highest production efficiency rates of selected crops (after DIEPENBROCK *et al.*, 1995; PIMENTEL, 1980)

Crop	*Country*	*Total input (MJ/ha)*	*Total output (MJ/ha)*	*Output / Input*	*MJ Output / labour hour*
Pecan (C_3)	Texas	4314	2668	0.62	201
Almond (C_3)	California	57505	44874	0.78	-
Grape (wine) (C_3)	California; irrigated	63936	63943	1.00	592
Sugar beet (C_3)	UK	124324	141487	1.14	2830
Banana (C_3)	Taiwan, South	69761	95809	1.37	31
Apricot (C_3)	California; irrigated	26061	44018	1.69	-
Soybean (C_3)	US, Georgia	15247	28012	1.84	1286
Sugar cane (C_4)	US, Louisiana	40380	73182	2.18	2439
Grapefruit (C_3)	US	31628	93348	2.96	510
Sorghum (C_4)	US, Texas; rainfed	7087	22571	3.18	2482
Rice (C_3)	Philippines	11713	39938	3.41	49
Rapeseed (C_3)	Germany	22754	93401	4.10	-
Barley (C_3)	Germany	26319	117543	4.47	-
Corn (C_4)	US, Illinois	25669	116726	4.55	14813
Wheat (C_3)	Germany	28570	133283	4.66	-

Table 4: Effects of latitude and cultivation practice on energy efficiency of selected crops (after PIMENTEL, 1980)

Crop	*Country*	*Total input (MJ/ha)*	*Total output (MJ/ha)*	*Output / Input*	*MJ Output / labour hour*
Banana	Hawaii	77760	63849	0.82	160
Banana	Australia, NSW	81190	52241	0.64	87
Banana	Taiwan, Central	58477	55143	0.94	22
Banana	Taiwan, South	69761	95809	1.37	31
Sugar beet	UK	124324	141487	1.14	2830
Sugar beet	US, California	305159	214742	0.70	5765
Sugar beet	US, Minnesota	177486	100883	0.57	3162
Sugar beet	Germany (2 horses)	135626	141905	1.05	163
Corn	Mexico, hand	221	28319	128.20	25
Corn	Mexico, oxen	3226	13708	4.25	36
Corn	US, California	30209	106756	3.53	3411
Corn	US, Texas	145164	113733	0.78	4852
Corn	US, Illinois	25669	116726	4.55	14813
Sorghum	Sudan, hand	332	12357	37.27	52
Sorghum	Nigeria, draft animals	11131	10285	0.92	88
Sorghum	US, Texas, rainfed	7087	22571	3.18	2482
Sorghum	US, Texas, irrigation	46444	72384	1.56	3977

Another, interesting example is shown here for Sorghum. Once again, the Output / Input ratio was maximal when an enormous labour input by hand was invested, but the resulting energy output per labour hour was low. However, as in the case of Sorghum grown in Nigeria, a large amount of labour input does not guarantee a high Output / Input ratio.

Very interesting is also the difference between irrigated and rainfed Sorghum grown in Texas. Although the total energy output of irrigated Sorghum was much higher than under rainfed conditions, and in consequence also the resulting energy output per labour hour, the Output / Input ratio was better in case of rainfed Sorghum. It seems that a lot of experience will be required in order to optimize the cultivation systems.

What kind of energy do we like to produce? In the example given in Table 5, Miscanthus has got the much higher Output / Input ratio compared to rapeseed; however rapeseeds can easily be processed to oil, which may be used as fuel. Hence, the value of the product should also be taken into consideration.

Table 5: Energy efficiency of rape seed vs. Miscanthus
Source: PUDE (2006)

Input items	*Energy efficiency comparison (kwh/ha)*	
	Rape (without straw)	*Miscanthus (25 t dry mass/ha)*
Soil management, seed dressing, seed bed	416	27
Fertilizer	3394	1062
Plant protection	504	32
Harvesting	157	1950
Soil management	-	19
Transport	98	959
Drying	191	13000 *
Processing to oil	1988	-
Sum Input (without processing to oil)	4760	17049
Sum Input (with processing to oil)	6748	-
Sum Output	12794	106250
Output/Input (without processing to oil)	2.7	6.2
Output/Input (with processing to oil)	1.9	-

* if winter conditions are cold enough, drying is superfluous for Miscanthus

Table 6: Estimates of eco-volume and bio-volume in Mexico, Chiapas, Huixtla (average of 6 years; source: data from Toledo Toledo *et al.*, 2005 and estimates derived from Janssens, 2005).

	Fresh matter yield (t/ha/year)			*Biometrical characteristics of sugar cane stand*					
	Cane	*Cane tops*	*Total*	*Eco-height d*	*Basal Area BA* (m^2/ha)	*Eco-volume* V_{eco} (m^3/ha)	*Bio-volume BA * d* (m^3/ha)	*Wesenberg* $w_b = V_{eco}/V_{bio}$	*Crowding intensity* $C_i = 100/w$ *(%)*
Green cane	125	18.7	143.7	2.46	131.0	24600	322.3	76.3	1.3
Burn 1x	96	14.4	110.4	2.09	97.5	20900	203.8	102.6	1.0
Burn 2x	89	13.3	102.3	1.97	72.3	19700	142.4	138.3	0.7
	Dry matter yield (t/ha/year)			*Energy content*					
	Cane	*Cane tops*	*Total*	*MJ/kg dry matter**	*Yield (GJ/ha)* Output	*Yield (GJ/ha)* Loss	MJ/m^3 *Eco-volume*	MJ/m^3 *Bio-volume*	*Gross photo-synthesis (t/ha/y)*
Green cane	41.7	6.3	48.0	18.0	864	0	35.1	2681	192
Burn 1x	32.0	4.8	36.8	18.0	662.4	201.6	31.7	3250	147.2
Burn 2x	29.7	4.5	34.2	18.0	615.6	248.4	31.2	4323	136.8

			Maximum power law		**Agricultural concentration**	**Bio-industrial concentration**
		→ Concentration path →				
Site	Atmosphere		**Eco-volume**	**Bio-volume**		e.g. **Bio-ethanol**
Active ingredient	CO_2 350 ppm	→	$(CH_2)_n$			C_2H_5OH
Energy status	0 MJ/m^3		$>$ 30 MJ/m^3	$>$ 2500 MJ/m^3		22600 MJ/m^3 (or 1000 l)

4 Efficiency of Bio-Productivity towards Bio-Energy Supply

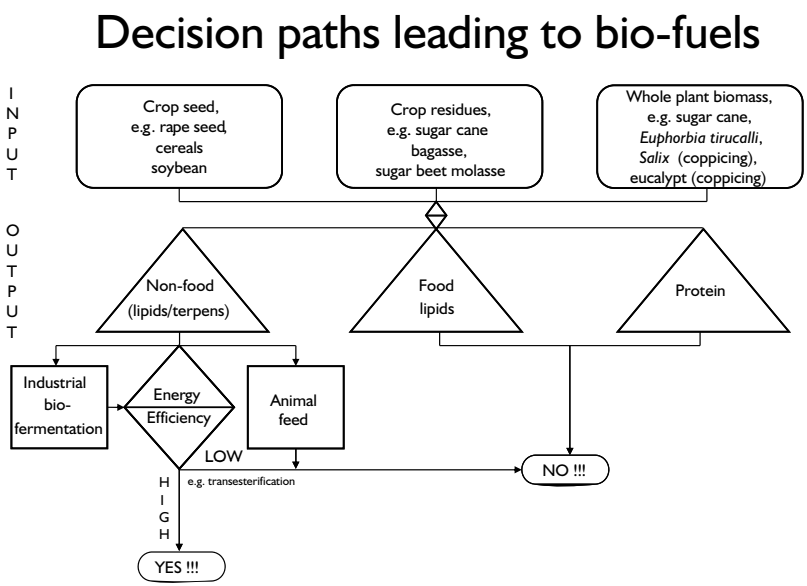
The following discussion is based on the results of a six-year case study with sugar cane in Chiapas, Mexico. A general observation in Chiapas is that after burning the size of sugar cane is reduced, which results in interesting changes of ecosystem parameters.

The fresh matter yield is reduced after burning, which results in a reduction of bio-volume (Table 6). Because the height of the stand, which is eco-height, is reduced as well, eco-volume is also smaller. Taking into account an equal energy content of 18 MJ per kg dry matter, the yield reduction results in a lower energy output. Interestingly, the energy content per eco-volume is slightly reduced, while that per bio-volume is increased by burning. In summary, agricultural practice here led to a concentration of energy, which is well in line with the concept of the maximum power law.

5 Concluding Remarks

The results may be summarized in a decision path leading to bio-fuels (Figure 1). Starting with crops such as rape seed, cereals, and soybean, crop residues from sugar cane or sugar beet, or whole plant biomass, for instance from sugar cane, *Euphorbia tirucalli*, Salix or eucalypt, the first question to answer is, whether it is a protein crop or, whether the product represents a food. In these cases it shall not be used for generation of energy. If the crop represents a non-food crop, in the ideal case, lipid and terpen-rich, it may be further consider as energy crops. The main question yet is the energy efficiency. If it is high, the crop may represent a valuable energy crop. If it is low, it may be considered for feeding cattle.

Figure 1: Decision paths leading to bio-fuels



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Effects of Biomass Ashes on Plant Nutrition in Tropical and Temperate Regions

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Abstract
The drastic rise of prices for commercial fertilizers is one of the main obstacles to increase the productivity in crop production, mainly in poor countries. The search for alternatives therefore becomes very important. The reutilization of residues from bionergy processes for plant nutrition is an important concern to save fertilizers and to implement nutrient cycling in agriculture. For this study ashes derived from bioenergy production were investigated. The effect of sugar cane ash (SCA) on lettuce and cucumber was investigated in Cuba and the effects of ashes from wood (WA), poultry litter (PLA), and rape meal (RMA) on ryegrass and oil radish were investigated in Germany. Special attention was given to phosphorus (P) availability. Positive yield effects and an increased plant P uptake were found when ashes were applied (mainly SCA and RMA). Investigation regarding the effect of PLA on soil P pools showed that the ash application may also result in an increase of readily available P contents in soil. Furthermore, an increased plant uptake of potassium was found. The results indicate that ashes derived from the energetic use of biomass may provide a suitable source for plant nutrition.

Keywords: poultry litter ash, wood ash, sugar cane ash, phosphorus, nutrient recycling

1 Introduction

Due to the drastic rise of prices for commercial fertilizers, the search for alternative fertilizer resources becomes increasingly important. The reutilization of residues from bionergy processes for plant nutrition is an important factor to save fertilizers and to realize nutrient cycling in agriculture. The ashes remaining from combustion of biomass are the oldest man-produced mineral fertilizers in the world. They contain nearly all nutrients except of nitrogen (N) and can help to improve plant nutrition (Bhattacharya and Chattopadhyay, 2002). Regarding phosphorus (P), the fertilizer effect of biomass ashes and the solubility of P in ashes are evaluated differently. Positive results were found, among others, by Nkana *et al.* (1998) for wood ash and Codling *et al.* (2002)

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for poultry litter ash. Mozaffari *et al.* (2002) found an increase of extractable soil P after application of alfalfa stem ash. In contrast, a negative effect of wood ash on the plant available P was found by Clarholm (1994). Besides being a source of nutrients itself, the application of biomass ashes may influence the form and availability of P by changing chemical parameters of the soil, mainly the pH (Muse and Mitchel, 1995). The fertilizer effect of ashes also depends on soil type, soil characteristics, and cultivated crops (Nkana *et al.*, 1998; Mozaffari *et al.*, 2002; Eichler-Löbermann *et al.*, 2008).

The urban agriculture in Cuba in so called "Organopónicos" started due to a high necessity for food production during the "*special period*". Currently it is the main source of vegetable production based on a substrate with high content of organic matter and nutrients. Since the application of highly soluble mineral fertilizers is prohibited by law in these cultivation systems (Koont, 2008), the use of biomass ashes can be an alternative for fertilization and nutrients recycling.

The objective of this study was to investigate the fertilizer effect of biomass ashes in different cropping systems in Cuba and Germany. Main emphasize was given to P.

2 Materials and Methods

2.1 Experiments in Cuba

The experiments with cucumber (*Cucumis sativus* L.) and lettuce (*Lactuca sativa* L.) were conducted under field conditions at the Organopónico "18 plantas" in Bayamo from December 2007 to March 2008. The substrate used in these plots was a mixture of soil and compost according to Minagri (1981). At onset of the experiment, the K content of the substrate was 130 mg/kg and the P content 72 mg/kg (Oniani method). The pH ($CaCl_2$) of the substrate was 6.56. The ash used in this study was derived from the combustion of sugar cane residues, and had a P content of 1.3 %.

In order to investigate the effect of sugar cane ash (SCA) on cucumber, 3 different treatments with 4 replications were established in a randomised block design. Each plot had 8 m^2. (Table 1). One control without ash was established as well a treatment with 6 t ash per ha. In the third treatment, 6 t ash were given to the previous crop (lettuce) to investigate the residual ash effect on cucumber. 90 days after sowing the cucumber plants were harvest from 1 m^2 subplots and dry mass determined after drying at 60 °C to constant weight. Additionally, length and diameter of fruits were measured on 5 plants.

In the lettuce experiment, 2 different treatments (with 6 T/ha and without ash) were investigated with 5 replications in a randomized block design (Table 1). Lettuce plants were harvested from 1 m^2 subplots 45 days after sowing and dry mass determined after drying at 60 °C to constant weight. Furthermore, 4 plants from each plot were taken to investigate the height of the plants and the leaf size.

During the vegetation time cucumber and lettuce plants were irrigated. The P content in plant shoot tissue (no fruits were analyzed) was measured after dry ashing using the vanadate-molybdate method (Page *et al.*, 1982).

Table 1: Treatments of the Cuban field experiments with sugar cane ash (1.3 % P)

Cucumber experiment	*Lettuce experiment*
Control - without nutrient supply	Control - without nutrient supply
SCA – sugar cane ash, 6 t/ha	SCA – sugar cane ash, 6 t/ha
SCA-R – residual effect of sugar cane ash (given at 6 t/ha to the previous crop)	

2.2 Experiment in Germany

In order to investigate the effect of 3 different biomass ashes on plant P nutrition a pot experiment was carried out. The soil used was taken from a long-term field experiment from a control plot on which no P fertilizer has been applied since 8 years. The soil texture was loamy sand. Following the FAO nomenclature, the soil is classified as Haplic Luvisol. The double-lactate soluble P content (P_{DL}) of 39 mg/kg soil indicates a severe P deficiency according to the German soil P classification (ANONYMUS, 2004). The double-lactate soluble soil K and Mg contents (113 and 117 mg/kg, respectively) indicate optimal supply.

Mitscherlich-pots were filled with 6 kg sieved and air-dried soil. Before sowing, each pot received a solution containing 1.4 g NH_4NO_3. Six different treatments were established with 4 replications each (Table 2). In order to separate the P and K effect of ashes, a treatment with KCl but without any P, and a treatment with triple superphosphate (TSP) but without any K was established beside the control and 3 ash treatments. Due to the differences in ash nutrient content (*agua regia* extract), the amount of nutrients given with the ashes varied between the treatments (Table 2). Two crops, oil radish (*Raphanus sativus* L.) and ryegrass (*Lolium westerwoldicum* L.) were grown in an open-air greenhouse. Distilled water was given according to plant requirement. Plants were harvested about 8 weeks after germination when they reached their maximum of biomass weight. Ryegrass was cut two times within the growing period.

Table 2: Treatments of German pot experiment and the amount of nutrients given (mg/pot)

Treatment	*Short name*	*Nutrients per pot*			
		N	P	K	Mg
control	Control	490	–	–	–
potassium (1 g KCl)	KCl	490	–	520	–
phosphorus (1 g TSP)	TSP	490	208	–	–
wood ash (8 g)	WA	490	16	32	48
poultry litter ash (8 g)	PLA	490	160	120	128
rape meal ash (8 g)	RMA	490	728	656	712

DM yield was determined after drying the harvested biomass in an oven at 60°C to constant weight. Total P content in the plant tissue was determined after dry-ashing using the vanadate-molybdate method (Page et al. 1982). Ca, K and Mg were measured photometrically. Soil samples were taken from each pot after harvest, air dried and sieved down to a particle fraction <2 mm. Water extractable P (P_W) was determined according to VAN DER PAAUW (1971). P concentration in this extract was determined by the phosphomolybdate blue method applied to flow injection analysis. Double lactate extractable P, K, and Mg, as well as the pH ($CaCl_2$) were determined as described by BLUME *et al.* (2000).

2.3 Statistical analyses

The data obtained were subjected to the analysis of variance. The means were compared by the Duncan multiple range test.

3 Results

3.1 Experiments with sugar cane ash in Cuba

For both tested crops a positive yield effect of SCA application was found. For cucumber, the direct fertilization with SCA had a better effect on yields than the residual effect of this ash (Tables 3, 4, 5). However, the residual effect was also found to increase the yield in comparison to the control. The ash application also affected the P uptake of cucumber plants. It was found to be highest in the SCA treatment, followed by the residual SCA treatment.

In lettuce, an increased number of leaves and positive effects on plant height and yield were found in the SCA compared to the control treatment. P uptake was found to be significantly higher in the ash treatment compared to controls (9.16 g/m^2 vs. 2.88 g/m^2, $p = 0.000$).

Table 3: Effect of application of sugar cane ash (SCA) on length and diameter of fruits (cm), yields of fruits (kg/m^2) and P uptake of shoots (g/m^2) of cucumber under field conditions.

	Control	*SCA*	*Residual SCA effect*
Lenght of fruits	20.33 ^{a}	29.21 ^{c}	23.41 ^{b}
Diameter of fruits	5.62 ^{a}	7.87 ^{c}	6.21 ^{b}
Yield of fruits	2.10 ^{a}	3.14 ^{c}	2.70 ^{b}
P uptake (shoot)	5.66 ^{a}	13.8 ^{c}	8.64 ^{b}

Different letters indicate significant differences between treatments, $p < 0.05$ (Duncan).

Table 4: Effect of application of sugar cane ash (SCA) on number of leafs, plant height and leaf size (cm^2) of lettuce under field conditions

Treatment	*Number of leafs**				
	20 Dec	*27 Dec*	*3 Jan*	*10 Jan*	*17 Jan*
Control	4.40	7.67	11.8	13.4	16.2
SCA	5.55	8.42	12.4	14.0	18.9
p	0.000***	0.002**	0.082	0,044*	0,000***

	*Plant height**			*Leaf size**
	3 Jan	10 Jan	17 Jan	
Control	3.59	7.27	18.7	342
SCA	4.22	8.00	21.4	340
p	0.002**	0,046*	0.000***	0.918

20 samples per treatment (ANOVA, Duncan 0.05).

Table 5: Effect of application of sugar cane ash (SCA) on yield (kg/m^2), P content (mg/kg DM) and P uptake (g/m^2) of lettuce under field conditions

Treatment	*yield*	P *content*	P *uptake*
control	1.65 ^{a}	1800 ^{a}	2.88 ^{a}
SCA	2.35 ^{b}	3900 ^{b}	9.16 ^{b}

Different letters indicate significant differences between treatments, $p < 0.05$ (Duncan).

3.2 Experiment with ashes from wood, poultry litter and rape meal in Germany

In tendency, the highest oil radish and ryegrass yields were obtained when rape meal ash (RMA) was applied (Table 6 and 7), although yield differences were not significant. However, for the first ryegrass cut a significant positive effect was found in the RMA treatment in comparison to the control (DM yield RMA: 10.35 g, control: 8.85 g, $p < 0.05$). The P uptake of both crops increased significantly when TSP, PLA, or RMA were supplied. The highest values were found in the RMA treatment, which was even higher than in the TSP treatment. No effects were found for WA on plant P uptake. The K uptake increased mostly when RMA or KCl were applied.

For treatment PLA and the control treatment, soil tests were carried out. Ash application significantly increased the readily available soil P pools ($\mathrm{P_W}$ and $\mathrm{P_{DL}}$) (Table 8). The $\mathrm{P_{DL}}$ nearly doubled when ash was applied. For oil radish slightly lower soil P contents were found than for ryegrass, probably due to higher P uptakes of oil radish. Due to the ash supply the average soil pH increased from about 5.7 to 6.6.

Table 6: Yield (DM, g/pot) and nutrient uptake (mg/pot) for ryegrass in the German pot experiment

Treatment	*yield 1*	*yield 2*	*yield total*	*Nutrient uptake total*				
				P	Na	K	Ca	Mg
control	8.85 ^{a}	3.50 ^{b}	12.3	54.9 ^{ab}	21.6 ^{c}	585 ^{a}	133 ^{c}	47.0 ^{b}
KCl	9.17 ^{a}	3.62 ^{b}	12.8	51.7 ^{a}	10.1 ^{a}	795 ^{b}	123 ^{bc}	41.4 ^{a}
TSP	8.92 ^{a}	3.47 ^{b}	12.4	67.2 ^{c}	23.5 ^{cd}	586 ^{a}	119 ^{b}	46.9 ^{b}
WA	9.25 ^{a}	3.55 ^{b}	12.8	56.2 ^{ab}	23.7 ^{cd}	606 ^{a}	129 ^{bc}	45.9 ^{b}
PLA	9.55 ^{ab}	2.72 ^{a}	12.3	62.6 ^{bc}	24.7 ^{d}	621 ^{a}	128 ^{bc}	40.9 ^{a}
RMA	10.77 ^{b}	2.73 ^{a}	13.5	90.6 ^{d}	16.7 ^{b}	785 ^{b}	99 ^{a}	45.6 ^{b}

Different letters indicate significant differences between treatments, $p < 0.05$ (Duncan)
Yield 1, 2 = dry matter yield of the first and second cut
TSP = TripleSuper-P, WA = wood ash, PLA = poultry litter ash, RMA = Rape meal ash

Table 7: Yield (g/pot) and nutrient uptake (mg/pot) for oil radish in the German pot experiment,

Treatment	*yield FM*	*yield DM*	*Nutrient uptake total*				
			P	Na	K	Ca	Mg
control	219 ^{a}	15.5	73.3 ^{ab}	43.1 ^{b}	560 ^{a}	446 ^{a}	52.9
KCl	238 ^{b}	15.6	70.3 ^{a}	35.4 ^{a}	780 ^{c}	422 ^{a}	50.2
TSP	218 ^{a}	14.8	95.2 ^{c}	47.5 ^{c}	558 ^{a}	465 ^{a}	48.4
WA	216 ^{a}	15.5	76.8 ^{ab}	51.0 ^{d}	581 ^{ab}	471 ^{a}	52.4
PLA	226 ^{ab}	16.6	84.9 ^{bc}	64.8 ^{e}	620 ^{b}	534 ^{b}	49.3
RMA	238 ^{b}	16.3	116.0 ^{d}	77.0 ^{f}	782 ^{c}	415 ^{a}	53.6

different letters indicate significant differences between treatments, $p < 0.05$ (Duncan)
Yield FM = yield of fresh matter, yield DM = yield of dry matter
TSP = TripleSuper-P, WA = wood ash, PLA = poultry litter ash, RMA = Rape meal ash

Table 8: Effect of poultry litter ash (PLA) on soil ph and P content (water soluble (P_W), double-lactate soluble (P_{DL}), mg/kg) in the German pot experiment.

Crop	*Treatment*	*pH*	P_W	P_{DL}
rygrass	control	5.8 ^{a}	2.9 ^{a}	38 ^{a}
	PLA	6.5 ^{b}	4.9 ^{b}	74 ^{b}
oil radish	control	5.7 ^{a}	2.4 ^{a}	33 ^{a}
	PLA	6.6 ^{b}	3.8 ^{b}	56 ^{b}

Different letters indicate significant differences between treatments, $p < 0.05$ (Duncan)

4 Discussion

A high nutrient effectiveness of biomass ashes was observed in the German, as well as in the Cuban experiments under different experimental design and climatic conditions. Generally, the ashes with higher nutrient contents seemed to have the better effects. Thus, in the German experiment best results were found for the RMA treatment, and the lowest effects were found for WA application.

Since ashes contain various nutrient elements, it is difficult to identify the fertilizer effect of a single element. However, main effects in the German experiment can be explained by P and K supply with the different ashes, as it became visible when compared to TSP and KCl treatments. Mg supply seemed do have lower impact on yields in this experiment. The plants Mg uptake was not higher in the ash treatment than in the control. Furthermore, probably the K:Mg antagonisms affected the Mg uptake, which was lowest in the RMA and KCl treatment (these treatments had the highest K uptake). Additionally, a high K uptake went together with low Na and Ca uptakes. Generally, Mg, Ca and K as a rule act as antagonists among each other in nutrient uptake (Järvan, 2004).

The comparatively low yield and nutrient uptakes in the WA treatment showed, that in our experiment the ash effect was mainly related to the nutrient supply and not (or only to a small extend) to the pH effect. In other studies good results were found with ashes derived from woody biomass. These results are often related to pH effect, which may increase the availability of nutrients in soil. Krejsl and Scanlon (1996) found increased dry matter of oat when wood ash was applied. Positive liming effects with wood ash were also found for wheat by Etiegni *et al.* (1991) and Huang *et al.* (1992), as well as for alfalfa and barley by Meyers and Kopecky (1998). Patterson *et al.* (2004a) found a positive effect of wood ash application on oil content of canola, but found that the ash used may also result in an enrichment of undesired elements like Zn and Cd in the rape seed oil. After wood ash application on an acid soil Muse and Mitchel (1995) found an increased Mehlich-1 extractable P, K, and Mg soil content and a yield increase of dallisgrass-fescue herbage.

The high P uptake as well as the increase of soil P contents may be due to a relatively high solubility of P in SCA, GMA and PLA. However, other studies demonstrated only a low to moderate solubility of P in ashes (Erich and Ohno, 1992; Clarholm, 1994). Codling (2006) found 82 % of the total P in poultry litter ash bound in the $H_2SO_4 - P$ fraction, which is only inadequately plant available. In own studies with different biomass ashes from burnt agricultural products, usually more than 90 % of P were soluble in citric acid (Eichler-Löbermann *et al.*, 2008). In general, higher P availability can be expected from agricultural biomass than from wooden biomass ashes (Obernberger, 1997). A fly ash from gasification of alfalfa stems showed a relatively high P availability with 63 % of the total P being soluble in ammonium citrate (Mozaffari *et al.*, 2000), whereas in wood ashes the plant available P content was between 0.33 % and 20 % (Clarholm, 1994; Patterson *et al.*, 2004b).

Beside these effects on chemical soil parameters, the ashes may also influence the physical soil parameters positively. In an experiment with coal fly ash and biogas slurry Garg *et al.* (2005) found a reduced bulk density, an increased saturated hydraulic conductivity and moisture retention capacity in soils.

The fertility of the so called organopónicos, as a special form of Cuban urban agriculture, usually is found to be high. This is mainly due to a high content of organic matter in the soils of up to 40 %. However, due to the year-round crop cultivation there are high nutrient outputs. Thus, according to the soil classification, the levels of P and K at the beginning of the experiment were suboptimal. Usually the nutrient balance is warranted by the application of compost products and bio-fertilizers (Terry *et al.*, 2002). The results show that the application of ashes from biomass combustion may have a positive effect in this production system. Since the pH at the beginning of the experiment was in optimum with 6.5, and a further increase due to the liming effect of the ash would not have any advantage, we expect the main ash effect to be due to the nutrient application. The amount of P applied with the ash was quiet high with 80 kg per ha. This may explain the high P uptake of cucumber and lettuce after SCA application.

5 Conclusions

The results underlined the fertilizer potential of biomass ashes under tropical and temperate conditions. Provided that the ashes are not loaded with harmful substances, the usage of those ashes is an important method for nutrient recycling in agriculture – even for food crop cultivation – and saving of nutrient resources.

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Local Productive Arrangements for Biodiesel Production in Brazil – Environmental Assessment of Small-holder's Integrated Oleaginous Crops Management

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Abstract

Sustainability assessments were carried out in small-holders' farms in four territories where productive arrangements have been organized for production of minor oleaginous crops under the Brazilian biodiesel program. The study aimed at checking local impacts of the biodiesel productive chains at the rural establishment scale, and promoting the environmental performance of the selected farms, henceforth proposed as sustainable management demonstration units. Assessments were carried out with the APOIA-NovoRural system, which integrates 62 objective and quantitative indicators related to five sustainability dimensions: i) Landscape Ecology, ii) Environmental Quality (Atmosphere, Water and Soil), iii) Socio-cultural Values, iv) Economic Values and v) Management and Administration. The main results point out that, in general, the ecological dimensions of sustainability, that is, the Landscape Ecology and Atmosphere, Water, and Soil quality indicators, show adequate field conditions, seemingly not yet negatively affected by increases in chemical inputs and natural resources use predicted as important potential impacts of the agro-energy sector. The Economic Values indicators have been favorably influenced in the studied farms, due to a steadier demand and improved prices for the oleaginous crops. On the other hand, valuable positive consequences expected for favoring farmers' market insertion, such as improved Socio-cultural Values and Management & Administration indicators, are still opportunities to be materialized. The Environmental Management Reports issued to the farmers, based on the presented sustainability assessment procedures, offer valuable documentation and communication means for consolidating the organizational influence of the local productive arrangements studied. These productive arrangements were shown to be determinant

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for the selection of crop associations and diversification, as well as for the provision of technical assistance and the stabilization of demand - conditions that promote value aggregation and income improvements, favoring small-holders' insertion in the market. More importantly, these locally organized productive arrangements have been shown to strongly influence the valorization of natural resources and environmental assets, which are fundamental if sustainable rural development is to take place under the emerging agro-energy scenario.

Keywords: sustainable agriculture, environmental management, rural development, biofuels, family agriculture

1 Introduction

The insertion of small-holders dedicated to oleaginous crops into biofuel production chains represents a new opportunity for rural development in Brazil. Two main circumstances are influencing this agronomic and economic movement. First, a strong intensification in the demand for vegetable oils in the international market, either for food or energy purposes, which has improved both prices and the negotiating capacity of farmers. Second, the special provisions brought about by the 'Social Fuel Seal' policy of the Brazilian Agency for Petrol and Biofuels and the Ministry of Agrarian Development, which offers tax exemptions to biodiesel mills (but not to farmers directly) that acquire their feedstock from registered family farmers (Portal do Biodiesel, 2005). Influenced by these circumstances, particular productive arrangements have been organized in the different territories where oleaginous crops are being directed toward biodiesel production throughout the country, under varying institutional contexts, forms of farmers' involvement, and cropping systems (Bindraban and Zuurbier, 2007).

Even if specific regarding the institutional and geographical characteristics of these different territories, all local productive arrangements for biodiesel have been fashioned around productive chains involving on the one hand the farmers, and on the other the crushing mills and biodiesel transformation plants. Furthermore, these two main social actors of the biodiesel production chains are accompanied by their own representations (farmers' associations and entrepreneurs' cooperatives), as well as by a host of stakeholders (rural workers' syndicates, governmental and non-governmental organizations, social movements, scientific research and technology transfer institutions, consumers' representations, etc.). If indeed small-holders are to find insertion in these production chains, and whether this development is to be environmentally sound and sustainable (Hill *et al.*, 2006), all these social actors must be involved, having a say in the definition of their territorial development goals.

One way to warrant and promote such a participatory involvement is to carry out environmental impact assessments (EIA), focusing the productive sector and dedicated public policies, and having the social actors partaking of the productive chains as mediators. EIA procedures can suitably support the development, selection, and transference of adequate management practices and technologies for the farmers, according to their availability of resources and technical capabilities (Rodrigues and Rodrigues, 2007).

The mediators involved in impact assessment procedures are here identified as social representations performing political roles for expressing the multiple objectives and interests of the local communities (Campanhola *et al.*, 2007). When considering oleaginous crops for biodiesel production, the definition *a priori* of a productive objective (that is, the agricultural dimension), within the context of the National Program for Production and Use of Biodiesel (PNPB, 2007), contributes for conforming the mediators' network, as well as for establishing their local sustainable development goals, in accordance with larger national objectives (Wright, 2006) defined in the public policy.

In this sense, a series of Delphi-type Workshops were carried out in four territories in Brazil, with the objective of evaluating the main socio-environmental impacts of biodiesel production chains (Rodrigues *et al.*, 2007). This research built upon the expertise and knowledge of the local mediators (in all four territories) about the observed and expected impacts of the increasing demand on oleaginous crops for biodiesel production. Based upon a set of 125 indicators encompassing agro-ecological and socio-environmental impacts (Monteiro and Rodrigues, 2006), these EIAs pointed out that the increasing demand imposed by the biodiesel market would be linked to important management intensification in all studied territories, boosting consumption of inputs, natural resources, raw materials, and energy. These impacts were considered as negative consequences of productive intensification, with associated risks onto water quality and the conservation of natural habitats. On the other hand, concerning socio-economic and managerial indicators, this productive intensification would be associated with improved farmers training and professional dedication, income generation and distribution, investment levels and land valorization, better worker qualification, and improved working conditions and employment quality (Rodrigues *et al.*, 2007).

In the present study, these observed and prospective impacts at the production chain scale, whether negative or positive, are examined against the actual field situations observed in selected rural establishments, in the same territories and local productive arrangements. The objective is to verify the extension of those impacts, and to provide environmental management recommendations for promoting the sustainability of the involved small-holders. Additionally, and based on the detailed analysis of the environmental performance of the studied establishments, assess the role of the local productive arrangements for the insertion of small-holders in the agro-energy market.

2 Materials and Methods

The sustainability assessments were carried out in selected rural establishments with the 'System for Weighed Environmental Impact Assessment of New Rural Activities' (APOIA-NovoRural) (Rodrigues and Campanhola, 2003; Rodrigues *et al.*, 2008). The APOIA-NovoRural System consists of a set of 62 indicators scaling checklists, formulated toward the systemic assessment of a rural activity at the rural establishment scale, according to five sustainability dimensions: i) Landscape Ecology, ii) Environmental Quality (Atmosphere, Water and Soil), iii) Socio-cultural Values, iv) Economic Values, and v) Management and Administration.

Evaluations were performed by quantitatively and analytically assessing the effects of oleaginous crop management on each and every indicator and automatically calculating impact indices, according to appropriate weighing factors (Figure 1). Impact indices are expressed as utility value (0-1.0 scale, with the baseline level defined at 0.7 - Bisset, 1987) for each indicator, then for the aggregated dimensions and the final sustainability index for the rural establishment.

Figure 1: Typical scaling checklist of the APOIA-NovoRural indicators system, showing the 'Local opportunity for qualified employment' indicator.

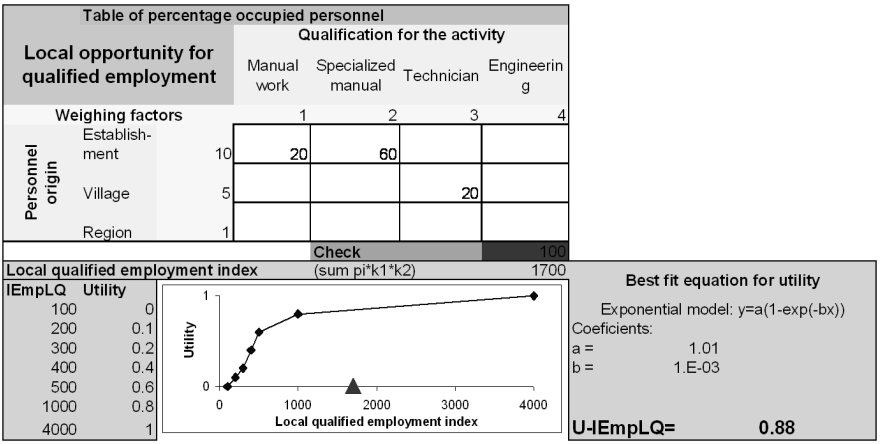


Table of percentage occupied personnel

Local opportunity for qualified employment		Qualification for the activity: Manual work	Specialized manual	Technician	Engineering
Weighing factors		1	2	3	4
Personnel origin: Establishment	10	20	60		
Village	5			20	
Region	1				
			Check		100

Local qualified employment index (sum pi*k1*k2) 1700

IEmpLQ	Utility
100	0
200	0.1
300	0.2
400	0.4
500	0.6
1000	0.8
4000	1

Best fit equation for utility

Exponential model: y=a(1-exp(-bx))

Coeficients:

a = 1.01

b = 1.E-03

U-IEmpLQ= 0.88

The utility functions built in the system express the environmental performance of the rural activity for each particular indicator, and were derived by probability and sensitivity tests, case by case, for each indicator (Girardin *et al.*, 1999). In the probability test, the indicator scale limits (maximum and minimum) and the baseline conformity value (0.7) are modeled, according to the numerical solution of the indicator variable (in the Figure 1 example, percent occupied personnel, according to origin and qualification). In the sensitivity test the indicator direction (whether positive or negative) and the meaning of the changes brought onto the indicator by the rural activity are modeled, according to the quantitative performance relationship defined in the sustainability baseline. These tests allow the construction of a correspondence table from impact indices to indicator utility values (in the Figure 1 example, IEmpLQ $= \sum$ pi*k1*k2 $=$ 1700), which is presented graphically in the scaling checklist. This correspondence relationship is then algebraically effected by a best fit equation, resulting in the expression of the impact index (in the given example, U-IEmpLQ $=$ 0.88; Figure 1).

Information required for filling out the APOIA-NovoRural scaling checklists are obtained in field surveys (aided by GPS, maps and satellite images) and data on the managerial and administrative history of the rural establishment provided by the farmer. Indicators related to water and soil quality are obtained in field and laboratory analyses. At the

conclusion of each assessment carried out with the APOIA-NovoRural System[1], an Environmental Management Report was issued to the farmer, for his/her decision making toward minimizing negative impacts and maximizing positive ones, contributing toward local sustainable development.

2.1 Study sites, local biofuels production programs, and institutional contexts

Study sites were chosen according to specific socio-environmental dynamics for oleaginous crops for biodiesel production in Brazil, considering two main aspects: (a) the organization of production associated with a well defined local market (industrial consumer), under a (b) consistent productive arrangement provided by some locally organized multi-lateral program or project, coordinated by local interaction among different social actors (or mediators). The enterprises (crushing mills and biodiesel transformation plants) perform an important role in determining the spatial reach of these local projects or programs, by promoting feedstock production and mechanisms for access to raw materials and inputs, as well as for final product distribution.

Four territories presenting these characteristics were selected for the proposed sustainability assessments, focusing small-holders' farms dedicated to crops that, even when considered secondary for biodiesel production, were managed under integrated energy-food crop associations, as follows: (i) Cássia (Minas Gerais State-MG) with integrated no-till forage turnip (*Brassica rapa* L.) / maize (*Zea mays* L.) rotation; (ii) São Raimundo Nonato (Piauí State-PI) and (iii) Irecê (Bahia State-BA) with integrated castor bean (*Ricinus communis* L.) / bush bean (*Phaseolus vulgaris* L.) production; and (iv) Belém (Pará State-PA) with oil palm (*Elaeis guineensis* Jacq.) production in a diversified context. Details of these studied establishments and their local productive arrangements are as follows.

2.1.1 Cássia

Located at 741 m altitude and 20°42'04" Latitude South and 46°52'24" Longitude West, in the ecological domain of the Atlantic Rain Forest, the municipality houses "Soyminas Biodiesel Derivado de Vegetais Ltda.", the industrial partner of the "Sowing Biodiesel Project" with the local Prefecture and associated family farmers. Two rural establishments were involved in the sustainability assessment field study in this territory. Establishment A (12 ha) was dedicated to maize production (10 ha) with forage turnip rotation in no-till integrated management. Establishment B (48 ha) produced maize (40 ha), half of which under no-till rotation integrated with forage turnip, besides some animal husbandry and a small orchard for self-consumption.

2.1.2 São Raimundo Nonato

Located at 403 m altitude and 08°56'18" Latitude South and 42°45'12" Longitude West, in the ecological domain of the semi-arid Arboreal Caatinga, the municipality supports the Project "Integrated and sustainable development of castor-oil agribusiness in the

[1] For details on the construction, validation, and usage of the APOIA-NovoRural indicators system see Rodrigues and Moreira-Viñas (2007), and for a copy of the operational spreadsheets, contact the authors.

Piauí semi-arid". The project is coordinated by Embrapa Meio Norte and involves the family farmers of a Bank of Northeast's rural colonization project, and the Micro and Small Enterprises Support Service of Piauí (SEBRAE-PI). Most of the castor-bean production from this area is destined to Brasil Ecodiesel Ltda. in Floriano (PI) and Crateús (Ceará State). The rural establishment (C) selected for the sustainability assessment (23 ha) cultivated castor beans integrated with bush beans in 3 ha as the main activity, with some maize and cattle raised in the collective area of the colonization project. Most of the area consisted of fallow and Caatinga secondary growth, without economic production.

2.1.3 Irecê

Located in the América Dourada district at 798 m altitude, 11°21'48" Latitude South and 41°33'42" Longitude West, in the ecological domain of the semi-arid Arboreal Caatinga, the rural establishment studied is a 50 ha tenancy (under long term, shared production and risk contract) without any infrastructure. The establishment (D) was sown to castor bean integrated with bush beans, under the "Castor Bean Varieties and Crop Rotation / Association Coordinated Program", carried out by Embrapa Cotton, CODEVASF-BA, and the "Cooperativa de Produção e Comercialização da Agricultura Familiar" (COOPAF). Most of the regional castor bean production is sent to Brasil Ecodiesel Ltda. in Iraquara (BA).

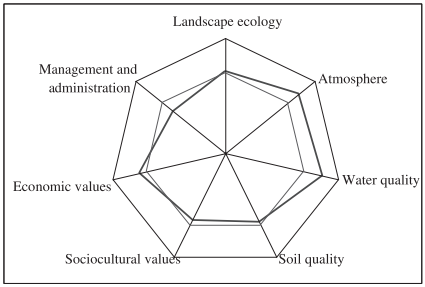
2.1.4 Belém

This study area focused the palm oil production chain, under the institutional arrangement of the "Programa Paraense de Incentivo à Produção de Biodiesel – Parábiodiesel". The sustainability assessment was carried out in a diversified rural establishment (E) located in Santo Antônio do Tauá, at 54 m altitude, 01°06'13" Latitude South and 48°07'34" Longitude West, in the ecological domain of the Equatorial Amazonian Rain Forest. The rural establishment studied (275 ha) had 192 ha under oil palm plantation, with a diversified productive base, including black pepper (28 ha), açaí palm (28 ha), lemon (5 ha), papaya (5 ha), cupuaçu (2 ha), pineapple (2 ha), noni (5 ha), and trees for plywood (5 ha). Only 2.5 ha corresponded to native forests in the establishment, notably occupying the permanent preservation areas shoring a small stream. Some small animal production was carried out for self-consumption.

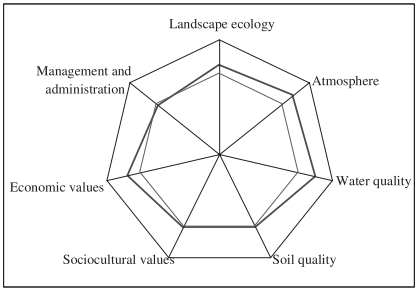
3 Results and Discussion

The field results obtained in the sustainability assessments in all rural establishments and studied territories, and concerning all oleaginous crops comprised in the present study were shown to be in contrast with the tendencies pointed out in the impact assessments carried out at the biofuels production chain scale (Rodrigues *et al.*, 2007). With results equal to or above the conformity sustainability level defined by the APOIA-NovoRural System (Figure 2), all establishments showed important contributions of the oleaginous crops management to sustainability, as well as evident opportunities for improvement, regarding the several sustainability dimensions and indicators evaluated.

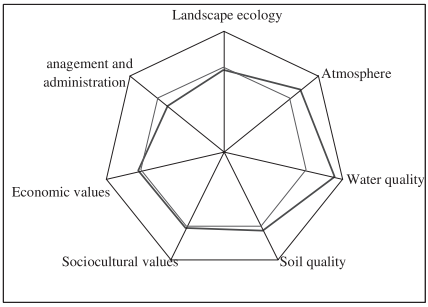
Figure 2: Sustainability assessments of rural establishments dedicated to oleaginous crops for biodiesel production, according to the evaluation dimensions of the "System for Weighed Environmental Impact Assessment of New Rural Activities" (APOIA-NovoRural).



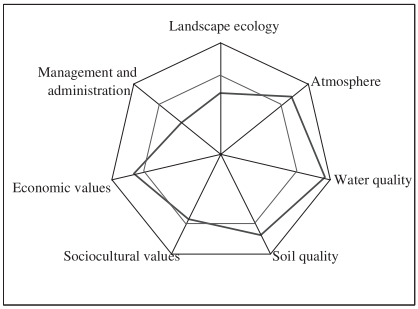
Establishment A, Cássia (MG)



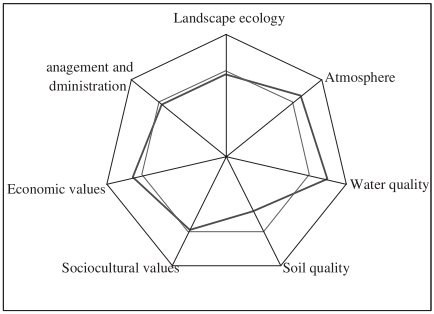
Establishment B, Cássia (MG)



Establishment C, São Raimundo Nonato (PI)



Establishment D, Irecê / América Dourada (BA)



Establishment E Belém / S A Tauá (PA)

Rural establishment location, oleaginous crop assessed	Mean sustainability index, all dimensions
Establishment A, Cassia (MG), forage turnip (*Brassica rapa*)	**0.73**
Establishment B, Cassia (MG), forage turnip	**0.77**
Establishment C, São Raimundo Nonato (PI), castor-oil plant (*Ricinus communis*)	**0.73**
Establishment D, Irecê (BA), castor-oil plant	**0.72**
Establishment E, Santo Antônio do Tauá (PA), oil palm (*Elaeis oleifera*)	**0.70**

Note: Results are mean values of indicators for each dimension. Thin lines represent the (0.70) sustainability conformity level, thick lines represent assessment result indices, in a utility values (0 – 1.0) scale.

The general mean sustainability index obtained when all establishments are considered (0.73) resulted from (a) near absence of negative impacts on the atmosphere, (b) quite adequate water quality and (c) generally favorable soil fertility improvements, as well as (d) overall positive economic indicators. On the other hand, the Management and Administration indicators were below the sustainability conformity level for all establishments, pointing out where there are major opportunities for sustainability performance improvement (Figure 2).

3.1 Establishment level analysis

3.1.1 Cássia, establishments A and B

Both establishments studied in this territory reached favorable final sustainability indices, with 80 and 88% of the 62 APOIA-NovoRural indicators showing results above the baseline conformity level defined in the method, respectively for establishment A (sustainability index = 0,73) and B (sustainability index = 0,77 - Figure 2). The local productive arrangement constructed under the 'Sowing Biodiesel Project' has been providing, on the one hand, improvements at the field level, contributing to productive efficiency by lowering the dependence on external inputs and resources, and favoring the recovery of soils and habitats, thus abating water contamination risks, while raising the living standards and economic security of participating farmers. On the other hand, by providing the institutional setting for cooperation among the several links of the local biodiesel production chain, from the farmers to the agro-industry, the Project has strengthened the relationship of the different groups of interest, fostering the territorial sustainable development. Adding to these results, three general difficulties have been pointed out by the farmers, concerning their productive capacity: i) severe wild bird attack onto germinating seeds; ii) lack of certified turnip seeds; and iii) severe losses (up to 30 - 40%) during harvest, due to inadequate machinery.

3.1.2 São Raimundo Nonato, establishment C

The association of castor bean with the bush bean crop traditionally grown by the farmer, brought about by the "Integrated castor bean agribusiness Project", has contributed most favorably (and perhaps most importantly) for improvement of the Economic performance indicators (mean index = 0.73) of this very modest producer. With a whole 40% of the 62 indicators below the conformity sustainability level (general index = 0.71), however, many opportunities are in place for improving this farmer performance, especially concerning the Management and Administration set of indicators (mean index = 0.60 - Figure 2), with special reference to the Farmer profile and dedication indicator components (index = 0.50). Namely, the implementation of accountability (to manage resources and finances) and planning practices should be emphasized in the technology transfer actions of the Project. Three main difficulties were named by the farmer: i) low value and excessive fringe costs (for minimum processing of the harvested beans) of the product; which engendered ii) inaccessibility to mechanization; and iii) to temporary workers for cultivation and harvest. An adequate solution could be access to credit directed toward acquisition of implements for animal traction, to be offered under the Project.

3.1.3 Irecê (América Dourada), establishment D

The crop situation studied consisted of castor bean only, with atypical spacing, because the bush bean crop had been lost to the season's severe drought. With 71% of the 62 indicators above the conformity sustainability level of the APOIA-NovoRural System, this establishment presented important limitations regarding the Landscape Ecology dimension (mean index = 0.54), owing to its lack of any natural habitats and null productive diversity (castor bean production only); and the Management and Administration dimension (mean index = 0.44), bringing the mean general sustainability index to a 0.72 value (Figure 2). Both of these dimensions' feeble performances were constrained by the land tenancy situation found in place, which discouraged the farmer's engagement to solve those particular deficiencies. This situation also influenced negatively some important Socio-cultural Values indicators (mean index = 0.65), such as deficient Employment quality (informality and lack of any fringe benefits, index = 0.30). These negative impacts were offset by excellent Soil quality and Economic performance indicators (mean indices = 0.82 and 0.79, respectively). Two main difficulties were pointed out by the farmer: i) the uncertainties of the regional climate and ii) complete absence of credit.

3.1.4 Belém (Santo Antônio do Tauá), establishment E

This establishment presented the most homogeneous performance among the assessed sustainability dimensions (mean index = 0.70), with the smaller amplitude of variation among indicators. Even though a whole 40% of the 62 indicators were below the conformity level of the Apoia-NovoRural System, no less than six of the 10 Soil quality indicators were well below the conformity level, biasing the results downwards (Figure 2). This result owed itself to the comparison between orchards and oil palm plantation for soil quality indicators assessment, which was justified because it is onto these orchards that oil palm is to be eventually expanded in the farm. High Productive areas management (0.97) and Productive diversification (index = 0.67) followed not from equitability of land use (70% under oil palm plantation) but from a valuable complement of other perennial crops (with a high Shannon-Wiener diversity index = 0.48), which favored other Landscape Ecology indicators, such as Natural habitats, Permanent Preservation Areas, and Threatened species protection. That same diversification was associated with good Economic Values performance (0.78). The farmer listed two important productive difficulties: i) very high costs for oil palm implantation, compared with current product value; and ii) severe losses imposed by the heart-of-palm-rotting disease.

3.2 Integrated sustainability dimensions analysis

When considering the environmental performances for the whole set of studied establishments, results show indices above or very close to the conformity level for the Landscape Ecology dimension of sustainability, except for establishment D (Figure 2). Most favorable indicators for those other establishments were related with 'Conservation of natural habitats' and 'Permanent Preservation Areas' (APP), 'Productive areas management', and 'Degraded land reclamation'. On the other hand, mandated 'Legal Preserve' (RL) conservation was a problem for all except establishment C, for the Legal Preserve in its case is collective, legally defined for the whole colonization project. Also, 'Land-

scape diversity' and 'Productive diversity' were low for all except establishment E. This latter indicator is a measure of the farmers' capacity to face prices instabilities, in the potentially volatile market of vegetable oils.

Regarding Atmosphere and Water quality indicators, quite favorable results were obtained in all establishments, while Soil quality indicators were mostly adequate, and improving under oleaginous crops management, for all except establishment E. All these indicators immediately concerned with ecological performance (Landscape Ecology and Environmental Quality dimensions of APOIA-NovoRural) attested to an adequate field situation (for the selected sample), opposed to the expectancy obtained in the socio-environmental impact assessments carried out at the production chain scale, which pointed out increased use of inputs and natural resources, with potential negative environmental consequences (Rodrigues *et al.*, 2007). This apparent favorable situation observed in the present set of environmental assessments calls for attentive management, in order to avoid eventual materialization of those expected negative impacts.

The feeble results for the Socio-cultural indicators pointed out the quite modest living conditions observed in most studied territories and establishments, only two showing results just similar the sustainability conformity level (0.70). 'Access to education', especially for the farmers; 'Opportunities for local employment', even if for non skilled workers; 'Employment quality', especially due to formality and social security observance; and 'Access to public services' weighed favorably for this general result, while 'Consumption standards' were very modest.

The Economic Values dimension showed quite favorable results for all studied establishments, especially due to good performance relative to 'Income generation' (considering income security, stability and amount), 'Income sources diversity', and 'Land value', which concerned improvements in productive conditions and infrastructure, even if associated with increased 'Indebtedness level', the main negative indicator for the studied establishments in this sustainability dimension.

Contrarily to social actors expectancies raised in the socio-environmental impact assessment at the production chain scale in all territories (Rodrigues *et al.*, 2007), the Management & Administration dimension of sustainability showed the main performance weaknesses in all studied establishments, strongly so for A, C, and D. Here rest the most valuable opportunities for improvements to be brought about by increased demand for oleaginous crops under the agro-energy context, for in general no heavy cash investments are required to obtain solutions – potentially low cost managerial, capacity building, and organizational ameliorations suffice.

For example, the 'Farmer profile and dedication' indicator showed deficiencies as basic as total lack of any accountability and of any planning systems, indispensable items if small-holders are to find their insertion into market settings. The 'Commercialization conditions' indicator pointed out deficiencies regarding widespread dependence on middlemen, and lack of processing, storage, and productive integration conditions in the studied establishments. The 'Residues management' indicator showed common prob-

lems, mostly for domestic wastes; while residues from production are, for the best cases, just incorporated as soil amendments, without treatment, composting, or conditioning.

The 'Institutional relationships' indicator showed as main deficiency the absence of continuous professional training for the farmers, possibly where the best potential for a performance shift lies. This is especially confirmed by the main positive results obtained in this same indicator, attesting to the presence of technical assistance and extension, as well as research and development institutions with close ties with all farmers studied, registering the presence of several local Producers Associations, Municipal Secretaries, and the institutions Embrapa, Emater, and Sebrae.

4 Conclusions

Regarding production of forage turnip, the positive socio-environmental impacts were corroborated by several known attributes of the plant: (i) fast and abundant growth even under winter conditions, out-competing weeds; (ii) extensive, acidity-resistant root system (up to 2 m long), favoring deep recovery of soil nutrients (especially N and P); (iii) good acceptability as forage and fodder for ruminants, as well as early and abundant flowering, excellent for bee feeding; and (iv) tolerance to most pests and diseases (Pereira, 1998).

In what concerns castor-oil, the high value for the fine chemistry industry and the relatively low level of technology still present in Brazilian producing areas are important constraints to make the crop viable for biodiesel production (de Mendes, 2005; Severino, 2006). Even with these constraints, castor-oil is still to be considered an important crop under the Biodiesel Program, due to its role as a value-adding cash-crop usually cultivated in association with food-crops such as maize and beans, as well as a means for small-holders to obtain access to technical assistance and training, when associated with biodiesel producing companies under the provisions of PNPB.

All favorable conditions contributed by the oil palm crop expressed by the social actors are also fully corroborated in the literature (Monteiro *et al.*, 2006), whereas the positive points regarding degraded lands occupation and recovery by oil palm plantations must be resolved, in conjunction with solutions to the problems of incorporation of new areas and native forest felling in many regions of the world (Annevelink *et al.*, 2007).

Even though each specific assessment overviewed in the present study has been constructed under its own environmental, managerial, and productive context - abating the meaningfulness of comparisons - the mean Sustainability Index obtained for the sample, above the conformity level defined in the assessment methodology, is a measure of the positive influence of the organized local productive arrangements and territorial projects to the environmental performance of the studied farms. This general conclusion, applicable to all regions and crops studied, has been corroborated in the literature (Haverkort *et al.*, 2007) by the argument that, more than a matter of specific crop or environmental setting, it is the local productive arrangement that defines the tendency of impacts caused by the integration of oleaginous crops into agro-energy production chains.

The insertion of small-holders into the biofuels market has also been shown to follow a similar trend, with all sustainability criteria and indicators being influenced by the local productive arrangements that determine favorable opportunities for crops association and diversification, the provision of technical assistance, and the certainty of a steady demand for production. These conditions may promote value aggregation and income improvements, security and stability over time, and most importantly a valorization of natural resources and environmental assets, under the frame of local development initiatives and community involvement. Sustainability assessment procedures, such as the one exemplified in the present study, offer valuable documentation and communication means for consolidating such initiatives.

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

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Keywords: biofuels, food demand, energy resources, greenhouse gas emissions

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

[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

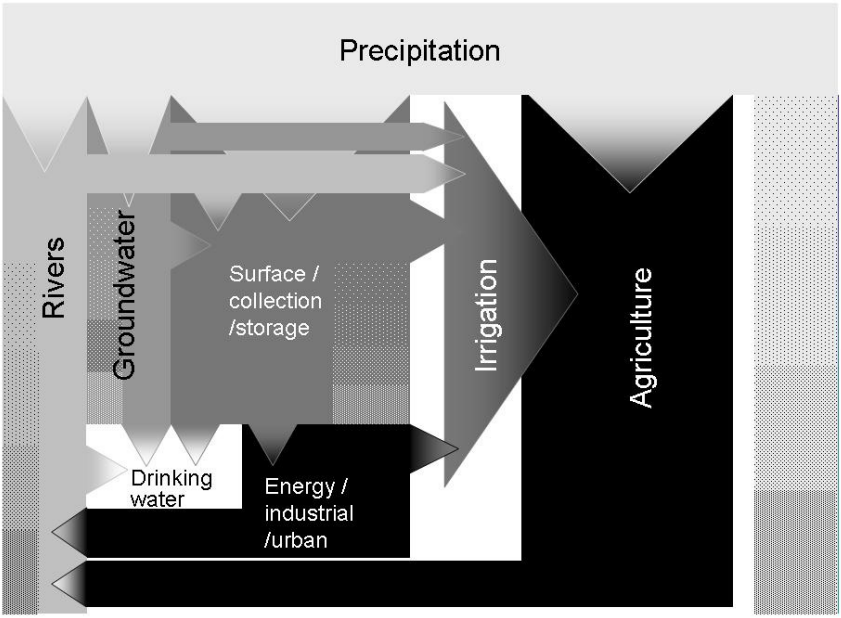
and biomass production for land and possible resulting price increases for food. This increasing competition is today widely acknowledged by many authors and has found its way into policy (BMZ, 2008). Under an aggressive biofuel growth scenario with productivity change and cellulosic conversion technology 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.

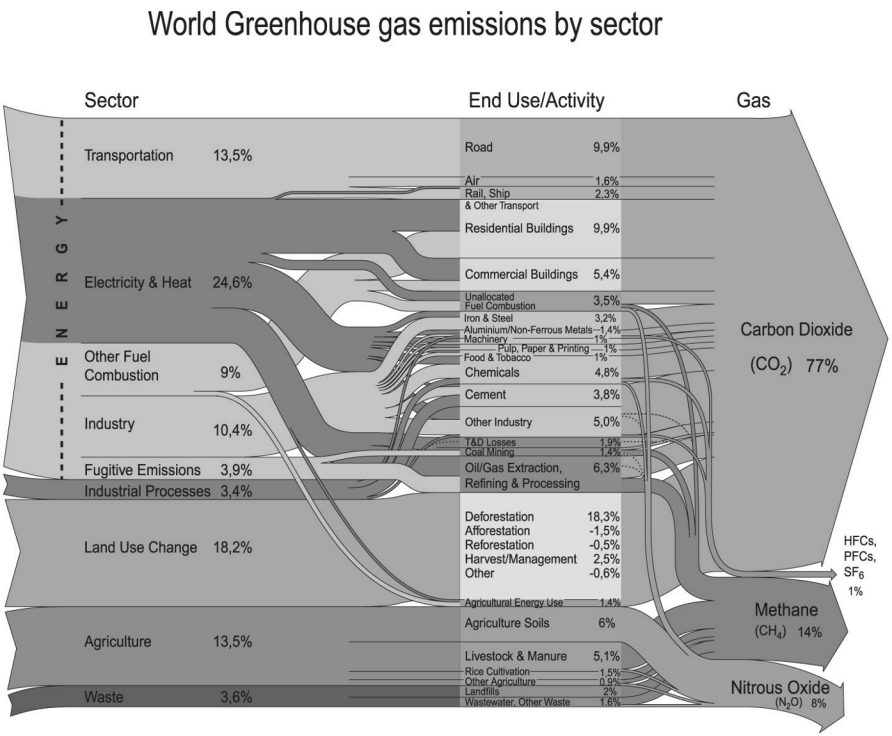
5 The Climate Angle

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-

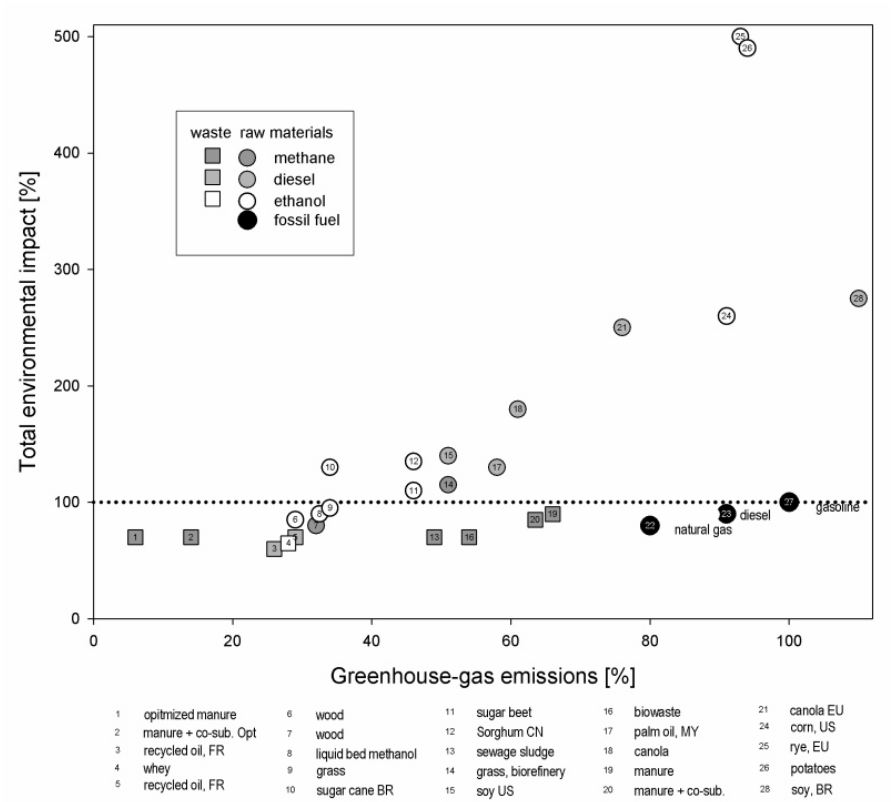
Figure 2: UNEP/GRID-Arendal, 'World Greenhouse gas emissions by sector', UNEP/GRID-Arendal Maps and Graphics Library, 2008, <http://maps.grida.no/go/graphic/world-greenhouse-gas-emissions-by-sector> [Accessed 17 October 2008]



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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Buchbesprechungen

Gunther Franke, Horst Mutscher, Albrecht Pfeiffer; 2009

Das Institut für tropische Landwirtschaft der Karl-Marx-Universität Leipzig 1960 bis 1992 – Zeitzeugen berichten

175 Seiten, 15 Anlagen, Engelsdorfer Verlag, Leipzig, 2009. ISBN 978-3-86703-812-6. Brosch., Preis: € 14,90.

Die Universität Leipzig begeht in diesem Jahr ihr sechshundertjähriges Jubiläum. Die Geschichte der Alma Mater Lipsiensis ist reich an weltbewegenden Erfindungen, geprägt von herausragenden Geistesschaffenden und Naturwissenschaftlern, aber auch gezaust von politisch bedingten Höhen und Tiefen.

Das Institut für Tropische Landwirtschaft Leipzig (ItL) wurde im Jahr 1960 gegründet, um den jungen Nationalstaaten eine Alternative für eine universitäre Ausbildung ihrer Talente bieten und im Rahmen der internationalen Zusammenarbeit materielle und personelle Unterstützung in Lehre, Forschung und Entwicklungsprojekten erhalten zu können. In den ersten vier Kapiteln werden dazu Fakten und Begebenheiten in chronologischer Reihenfolge sowohl vor als auch nach der Gründung des ItL dargelegt. Im Kapitel 5 sind detailliert und facettenreich der Werdegang von Ausbildung, Forschung, Auslandstätigkeit, Publikationstätigkeit und personeller Entwicklung des Institutes abgehandelt. Logisch schließt sich daran im Kapitel 6 die Vorstellung der einzelnen Wissenschaftsbereiche an. Die Autoren ließen hierbei den Mitarbeitern freie Hand. Dies führte nicht nur zu einer recht unterschiedlichen Rangfolge in der Wertung von Aktivitäten und Ergebnissen, sondern ermöglichte auch eine unausgewogene Selbstdarstellung einiger Ko-Autoren. Im Kapitel 8 befassen sich die Autoren mit der Stellung des ItL in der Zeit des Umbruchs und der Wiedervereinigung Deutschlands. Die Vorgänge in den Jahren 1990 und 1991 sind vollständig aufgeführt, wiederspiegeln den Zustand des ItL und führen die Argumente der Befürworter für eine „Gesamtdeutsche tropische Landwirtschaft“ auf. Demgegenüber ist die Periode der Abwicklung von 1992 bis 1996 sehr karg abgehandelt und lässt vermissen, dass der verbliebene Lehrkörper und die wissenschaftlichen MitarbeiterInnen auf hohem internationalem Niveau die Ausbildung von Magisterstudenten und Doktoranden garantierten, ohne selbst eine beruflich relevante Perspektive erhalten zu haben.

Abschließend sind in 15 Anlagen auf insgesamt 55 Seiten fast lückenlos die historischen Abläufe des ItL, die statistischen Daten zu den Absolventen im Direkt- und Postgradualstudium, die Publikationen, die Internationalen Sommerseminare und nationalen wissenschaftlichen Tagungen, die Tagungen des „Gemeinsamen wissenschaftlichen Rates der Partnereinrichtungen für tropische und subtropische Landwirtschaft

im RGW“, Kooperations- und Forschungspartner und die wissenschaftlichen Mitarbeiter des Lehrkörpers sowie die Leitungsstrukturen der einzelnen Wissenschaftsbereiche zusammengestellt.

Heute konterkarieren die Absolventen des ItL die Fragwürdigkeit der politisch motivierten Entscheidungen zur Abwicklung. Sie fungieren in höchsten akademischen Positionen im universitären Bereich, sind in herausragenden Positionen an Internationalen Institutionen tätig, managen erfolgreich Privatbetriebe oder geben ihr in Leipzig erworbenes Wissen im staatlichen Sektor ihrer Heimatländer sowie in NGO‘s weiter.

Jürgen Pohlan, Goethestadt Bad Lauchstädt

Ulrike Bartels, Claudia Heib, Daniela Ristau; 2009

Deutschland mit anderen Augen Erfahrungsberichte von Menschen mit Migrationshintergrund

152 Seiten, 20 s/w Fotos, Horlemann Verlag, Bad Honnef, 2009. ISBN 978-3-89502-276-0, Brosch., Preis: € 14,90.

Eine Reise in die deutsche Kultur, eine Suche nach deutschen Identitäten, unternommen von Menschen aus anderen Kulturkreisen, diesem wird in 20 Porträts von Menschen, die aus Afrika, Asien und Lateinamerika stammen, nachgegangen. Sehr persönlich und in lockerem Ton erzählen sie uns, aus welchen Gründen sie nach Deutschland gekommen sind, welche Bilder und Vorstellungen sie dabei hatten und wie sie das Leben in Deutschland wahrnehmen. Die Perspektiven sind vielfältig und unterschiedlich, die Erfahrungen mal widersprüchlich und mal übereinstimmend.

Dies wird in den Kapiteln Magnet Deutschland, (Oder: Was das Land attraktiv macht); Made in Germany, (Oder: Von Wirtschaftswunder, Wohlstand und Konsumgesellschaft); Krisensymtome, (Oder: Jammern auf hohem Niveau?) und Modernes Nomadentum, (Oder: Leben zwischen Migration und Integration) beschrieben.

Sehr deutlich wird aufgezeigt, dass Fragen der Integration und des friedlichen Zusammenlebens von Menschen unterschiedlicher Ethnien, Religionen und kultureller Prägungen unsere Zukunft beeinflussen. Alle Beteiligten müssen daran arbeiten und Integrationsprozesse werden nur gelingen, wenn sie auf Gegenseitigkeit und demokratischen Dialog aufbauen. „Erkenne dich selbst“ als Königsweg für das Erkennen des „Anderen“.

Ein lesenswertes Buch für den interkulturellen Dialog und besonders für die, die in der Entwicklungszusammenarbeit tätig sind.

Hans Hemann, Witzenhausen

Notes to authors

The Journal of Agriculture in the Tropics and Subtropics publishes papers and short communications dealing with original research in the fields of rural economy and farm management, plant production, soil science, animal nutrition and animal husbandry, veterinary hygiene and protection against epidemics, forestry and forest economy.
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Manuscripts are accepted in German, English, French, and Spanish. Papers may not be published in the order of receipt, those that require minor amendments, only are likely to appear earlier. Authors are advised to retain one copy of the manuscript themselves as the editors cannot accept any responsibility for damage or loss of manuscripts.

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