# ANALYSING THE EFFECT OF BIOFUEL EXPANSION ON LAND USE IN MAJOR PRODUCING COUNTRIES

## EVIDENCE OF INCREASED MULTIPLE CROPPING

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# SUMMARY

Existing estimates on the potential impacts of biofuel production are often based on projections made with models that have limited ability to incorporate changes in land use (notably cropping intensity). This paper studies biofuel expansion in 34 countries (Brazil, the USA, Indonesia, Malaysia, China, Mozambique, South Africa plus the 27 member states of the EU) between 2000 and 2010. In 2010, these countries produced 86 billion litres of ethanol and 15 billion litres of biodiesel, representing 97% and 77% of global production, respectively.

Key data on crop production and conversion were used to calculate biomass and land requirements for main biofuel crops. Between 2000 and 2010, biofuel land use in the study area increased by 25 million ha, of which 11 million ha is associated with co-products: by-products of biofuel production processes that normally are used as animal feed. During the same period, agricultural land in the study area decreased with 9 million ha. It expanded by 22 million ha in Brazil, Indonesia, Malaysia and Mozambique while 31 million ha was lost in the USA, the EU and South Africa. Main causes for loss of agricultural land are urbanization, industrialization, expansion of infrastructure, nature and forest development and land abandonment.

Increases in cropping intensity since 2000 generated 42 million ha of additional harvested crop area. Together with increased feed (co-product) availability, this was sufficient to increase Net Harvested Area (NHA, crop area harvested for food, feed and fibre markets) in the study area by 19 million ha. Thus, despite substantial expansion of biofuel production, more land has become available for non-fuel applications. Biofuel crop areas and NHA increased in most major biofuel producers including the USA and Brazil.

It is concluded that biofuel expansion between 2000 and 2010 is not associated with a decline in NHA available for food crop production. It is not the main cause of loss of agricultural area, while net crop production for non-biofuel use has increased.

The outcome of this study is surprising as it contradicts projections from modelling studies. However, modelling studies seem to have overlooked (impacts of) increases in multiple cropping. These changes should be considered as adaptations to increased demand for crop biomass, and they should be considered more fully in calculations of (indirect) land use change.

# Table of contents

# 1. INTRODUCTION

Increased biofuel production has been criticised for its potential impact on food availability, while it is feared that rising demand for crop land will cause deforestation and grassland conversion. Carbon releases from associated land use change are expected to undermine reductions in Greenhouse Gas (GHG) emissions. The main point of criticisms is based on expected impacts of biofuel production that will be caused by the introduction of dedicated biofuel policies since 2005. Policy evaluations mainly have been analysed using economic models (Banse et al., 2010; Al Riffai et al., 2012; Elobeid et al., 2012).

Commonly used economic models in biofuel policy evaluation include multi market partial equilibrium models like the FAPRI-CARD, ESIM, and IMPACT model, and Computable General Equilibrium (CGE) models like the Global Trade Analysis Project (GTAP), LEITAP and the Modelling International Relationships in Applied General Equilibrium (MIRAGE) model. Most models were originally developed to evaluate agriculture or climate policies and were later adapted to incorporate biofuel production (Pérez Domínguez and Müller, 2008; CBES, 2009, Khanna and Zilbermann, 2012). This has consequences for the way they have been implemented. Early applications, for example, did not consider generation of co-products (by-products of the biofuel production process which are mostly used as animal feed) (see, for example, Banse et al., 2010; Golub and Hertel, 2012) while second generation biofuel production technology originally was not included (Pérez Domínguez and Müller, 2008).

Other restrictions include limited ability to adjust to accelerations in yield improvement (Golub and Hertel, 2012) or to changes in crop rotation (Beach et al., 2012). Models do not consider double-cropping (cultivation of two or more crops on the same plot within a given year), while changes in fallow or other unmanaged land can only be accommodated to a certain extent (Keeney and Hertel, 2008), which is considered a significant drawback (Golub and Hertel, 2012). Changes in programs offering farmers compensation for not cultivating arable land (Conservation Reserve Program in the USA and Set-Aside in the EU), for example, were often not adequately included. Models further are not fully considering impacts of trade policies (e.g. preferential biofuel imports; Keeney and Hertel, 2008), crop tillage (Rosegrant et al., 2008), or agro-ecological conditions in crop production areas.

While the exact consequences of these limitations remain unclear, there is risk that relevant changes in crop production patterns, partly triggered by biofuel policies, may not be sufficiently covered in the analysis. Scenarios for future crop production published by FAO suggest that increasing cropping intensity will be an important source of additional crop biomass. According to Nachtergaele et al. (2010), cropping intensity is projected to increase with 4% in developing countries between 2006 and 2050. For developed countries, however, this will be 7%. Global average is projected to increase with 6%.

Central in the debate on the impact of biofuel production is the question to what extent current policies are causing alienation of land from food and feed production. Key is the way increased biomass requirements are to be met by area expansion, yield improvement or by increased cropping intensity. Bruinsma (2009) estimated that 80 percent of the projected growth in crop production in developing countries up to 2050 would come from intensification in the form of yield increases (71 percent) and higher cropping intensities (8 percent).

Higher shares are projected in land-scarce regions like South Asia and the Near East/North Africa where increases in yield would need to compensate for the foreseen decline in the arable land area. Arable land expansion will remain an important factor in crop production growth in many countries of sub-Saharan Africa and Latin America; although less so than in the past.

Given the large (be it mostly temporal) increases in crop prices, the general expectation that biofuels will permanently push up demand for food crop biomass plus the fact that farmers in the past have shown to be able to respond effectively to changes in crop demand, these expectations may have to be adjusted. Especially the projected increases in cropping intensity may be on the low side. Using data for 1962-2007, OECD-FAO (2009) for example calculated that half of the realized increases in harvested area were attributable to increased cropping intensity (the other half been related to area expansion).

More recently, reduction of (fodder and) CRP area and increased double-cropping have been reported for the USA (Wallander et al., 2011). About 16 percent of 2008 corn and soy bean farms brought new acreage into production between 2006 and 2008. The uncultivated land brought into production by these farms accounted for approximately 30 percent of the average farm’s expansion in total harvested acreage.

Most acreage conversion came from uncultivated hay. According to the farm survey, 15% of corn and soy bean farms reported a harvested acreage (summing up all crops) exceeding their arable area in 2008, which can only be explained by double-cropping. These farms reported higher expansion in harvested biofuel crop acreage than did other farms, suggesting double-cropping is a quick and effective way to generate additional biofuel crop biomass.

Given the scope of their limitations, economic model impact assessments of biofuel policies should be considered with care. Consequences of the limitations on the modelling outcome are difficult to assess but they may be considerable. Introduction of co-products in a GTAP evaluation of USA and EU biofuel policies, for example, was assessed to reduce the need for land conversion with 27 percent (Khanna and Zilbermann, 2012).

According to Croezen and Brouwer (2008), scenarios including second generation biofuel technologies resulted in land use requirements that were 50 percent lower as compared to scenarios which did not include lignocellulosic biofuel conversion technologies.

Summarizing, the use of information retrieved from economic model scenarios tends to be based on incomplete information sets and in this respect could generate misleading estimates. Much is related to issues of crop rotations, fallow and cropping intensity. One specific element is the lack of representation of local crop production conditions, e.g. information on soils or input use. This could give an incorrect impression with respect to day-to-day crop management practices such as input use efficiency. Consequently, perspectives for (sustainable) biomass production for biofuel and food/feed applications may be estimated incorrectly.

It is of the highest importance to use correct data for evaluations of biofuel policy impacts. This paper is to assess different sources of biomass production increases for eight major biofuel producers. We analyse biofuels and feedstock production increases of major biofuel feedstocks between 2000 and 2010, and their impacts on land use in Brazil, the USA, the EU, China, Indonesia, Malaysia, South Africa and Mozambique. Together, these countries represent a large majority of global biofuel production. For reasons of conciseness, they will be referred to as ’study area’. Local conditions for crop and biofuel production will be described in a generalized way.

In our analysis, we calculate land and biomass balances. Starting from the amount of biofuels produced, the required amount of biomass is calculated. This is used to derive the need for land related to biofuel production. By doing so, this paper has benefited tremendously from detailed material that has been collected and analysed for a book on biofuel crop production systems currently in preparation.

This report is organized as follows. Section 2 describes methodology that has been used in the analysis. Section 3 presents the main results, referring to available land resources, land use, and implications of biofuel expansion. This is followed by a discussion (Section 4) and some conclusions (Section 5).

# 2. METHODOLOGY

It is of the highest importance to use correct data for evaluations of biofuel policy impacts. This paper is to assess different sources of biomass production increases for eight major biofuel producers. We analyse biofuels and feedstock production increases of major biofuel feedstocks between 2000 and 2010, and their impacts on land use in Brazil, the USA, the EU, China, Indonesia, Malaysia, South Africa and Mozambique. Together, these countries represent a large majority of global biofuel production. For reasons of conciseness, they will be referred to as 'study area'. Local conditions for crop and biofuel production will be described in a generalized way.

In order to determine the impact of biofuel policies, production volumes will be compared to those of 2000, clearly before most countries introduced biofuel-related policy measures. An important distinction will be made between the amount of biomass (crop feedstocks) that is used to generate biofuels, the amount of land that is needed to produce the biomass, and the average number of harvests that can be generated from arable land (resulting from the prevalence of fallow and double-cropping in a given region). The paper will make use of the following concepts:

- 'Harvested area', i.e. the amount of crop area that is harvested in a country or region in a given year. This is not similar to the amount of arable land, as land may be harvested several times, while fallow land is not harvested at all

- 'Agricultural area', area of agricultural land in a given country or region. This includes arable land (cultivated with arable crops, i.e. food and feed crops), permanent grassland and agricultural tree crops (fruits, beverages, stimulant crops)

- 'Cropping intensity', a measure of harvested crop area per unit of arable land[1].

The relation between these concepts is defined by the following equation:

- Harvested area = agricultural area * cropping intensity

In our analysis, much attention is given to the calculation of (changes in) available agricultural area, harvested area and biomass available for non-biofuel applications (food, feed, fibres). This requires the calculation of full land and biomass balances.

Starting from the amount of biofuels that is produced in the study area, we calculated the amount of biomass that has been used in biofuel production chains. This is used to derive the need for land related to biofuel production. By doing so, this paper has benefited tremendously from detailed material that has been collected and analysed for a book on biofuel crop production systems currently in preparation[2].

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1 Note: this is not similar to the intensity of crop production (amount of inputs used per ha or amount of yield realized per ha).

2 Langeveld H, Dixon J, van Keulen H (eds.). Biofuel cropping systems. Carbon, land and food. Earthscan (expected in 2013).

# 3. RESULTS

## Land resources

An overview of land cover and land use in the study area is presented in Table 1. China, Brazil and the USA are the largest countries, Brazil having the largest forest area (nearly 40% of the study area total). Agricultural area is high in the China, the USA and (on a relative scale) the EU, Mozambique and South Africa. Most arable land is found in the USA, China and EU, permanent grasslands being important in the China (hosting more than one third of the study area grassland), USA and Brazil.

We calculated cropping intensity, expressed as sum of all harvested crop area during a given year divided by the total arable land (the Multiple Cropping Index or MCI). MCI was originally introduced as a measure for cropping intensity of tropical farming systems (Beets, 1982), but can be calculated for temperate regions as well (see, e.g. OECD-FAO, 2009). MCI in the study area varies between 0.53 in South Africa and 1.45 in China. It is around 0.8 in Brazil, the USA and the EU, Indonesia, Malaysia and Mozambique taking intermediate positions.

Table 1 Land cover and land use (million ha)

| Region | Land area | Forest | Agricultural area | Permanent grassland | Arable area | Multiple Cropping Index (-) |
|---|---|---|---|---|---|---|
| Brazil | 846 | 520 | 273 | 196 | 50 | 0.86 |
| USA | 914 | 304 | 411 | 249 | 160 | 0.82 |
| EU | 418 | 157 | 187 | 68 | 107 | 0.84 |
| Indonesia and Malaysia | 214 | 115 | 62 | 11 | 25 | 1.21 |
| China | 933 | 207 | 519 | 393 | 111 | 1.45 |
| Mozambique | 88 | 39 | 49 | 44 | 5 | 1.08 |
| South Africa | 121 | 9 | 97 | 84 | 13 | 0.53 |

Source: FAOSTAT (2013)

## Biofuel production

Sugar cane is the predominant feedstock for ethanol production in tropical regions (Table 2). In temperate areas, ethanol is mostly made from cereals (corn in the USA and China, wheat in the EU and China). Main biodiesel feedstocks are soy bean (Brazil, USA), rapeseed (EU) and oil palm (Indonesia and Malaysia). Feedstocks of minor importance, like castor beans in Brazil, sunflower and oil palm in the EU and Jatropha in Mozambique, are not included in the analysis.

Large differences exist in the way fields are prepared. Dominant practices relevant for the performance of the biofuel production chain include pre-harvest burning in sugar cane and ploughing for arable crops. Burning leaves of sugar cane is common practice before manual harvesting as sharp leaf edges are causing many injuries to labourers This is causing a considerable loss of leaf material and soil organic matter, while emissions of particulate matter cause a threat to lungs of the labourers This practice is gradually being phased out in Brazil where mechanic green harvesting is getting more and more common.

Table 2 Biofuel production chains included in the analysis

| Region | Feedstock | Biofuel | Field preparation | Input use |
|---|---|---|---|---|
| Brazil | Sugar cane | Ethanol | Pre-harvest burning is phased out | Moderately low |
| Brazil | Soy bean | Biodiesel | Mostly no-till | Low |
| USA | Corn | Ethanol | Mostly ploughed | High |
| USA | Soy bean | Biodiesel | Half under no-till | Moderately low |
| EU | Wheat | Ethanol | Ploughed | High |
| EU | Rapeseed | Biodiesel | Ploughed | High |
| EU | Sugar beet | Ethanol | Ploughed | Moderately high |
| Indonesia and Malaysia | Palm oil | Biodiesel | Pre-harvest burning | Moderately low |
| China | Corn | Ethanol | Ploughing | Very high |
| China | Wheat | Ethanol | Ploughing | Very high |
| Mozambique | Sugar cane | Biodiesel | Pre-harvest burning | Moderately high |
| South Africa | Sugar cane | Biodiesel | Pre-harvest burning | High |

Source: FAOSTAT (2013)

Ploughing arable fields, causing loss of soil carbon, is common in the EU and China, but less so in the Mid West of the USA and soy bean cultivation in Brazil. Use of fertilizers and agro-chemicals is highly variable. Input use is low to moderately low in Brazil, soy bean cultivation in the USA, Indonesia, Malaysia and Southern Africa. It is high in the production of cereals (USA, EU, and China) and rapeseed. Sugar beet is taking an intermediate position.

Main output data are presented in Table 3. Crop yield is high for sugar cane (Brazil, South Africa), sugar beet and oil palm. Cereal yields are high for corn in the USA, but less so for corn and wheat in the EU and China. Rapeseed and soy bean yields are modest. Ethanol yields are highest for sugar beet, and sugar cane (Brazil). Highest biodiesel yields were observed for oil palm. Generation of co-products is also quantified, as these can be applied in the livestock industry.

Major biofuel crops are well established feed crops, which holds especially for corn and soy bean Co-products considered in this study include dried distillers' grains with solubles (DDGS), soy meal, rapeseed meal, beet pulp and palm meal. It was decided to use a simple mass balance approach to distinguish between crop biomass used for biofuel production and for feed applications. Biofuel land claims were calculated by allocating a share of total land use according to the ratio of total crop feedstocks used for biofuels.

Co-product yields were calculated using conversion data and converted into tons per ha which allows better comparison. Co-product yields are high for corn (USA), oil palm and sugar beet. Yields are low for rapeseed and soy bean, while no co-products for the food or feed market are generated by sugarcane-ethanol.

Table 3 Crop, biofuel and co-product yields

| Region | Feedstock | Crop yield | Biofuel yield | | Co-product yield |
|---|---|---|---|---|---|
| | | (ton/ha) | (l/ha) | (GJ/ha) | (ton/ha) |
| Brazil | Sugar cane | 79.5 | 7,200 | 152 | - |
| Brazil | Soy bean | 2.8 | 600 | 18 | 1.8 |
| USA | Corn | 9.9 | 3,800 | 80 | 4.2 |
| USA | Soy bean | 2.8 | 600 | 18 | 1.8 |
| EU | Wheat | 5.1 | 1,700 | 37 | 2.7 |
| EU | Rapeseed | 3.1 | 1,300 | 43 | 1.7 |
| EU | Sugar beet | 79.1 | 7,900 | 168 | 4.0 |
| Indonesia and Malaysia | Oil palm | 18.4 | 4,200 | 90 | 4.2 |
| China | Corn | 5.5 | 2,200 | 46 | 2.9 |
| China | Wheat | 4.7 | 1,700 | 36 | 2.5 |
| Mozambique | Sugar cane | 13.1 | 1,100 | 23 | - |
| South Africa | Sugar cane | 60.0 | 5,000 | 107 | - |

Source: crop yields calculated from FAOSTAT (2013). Biofuel and co-product yields calculated from literature

Ethanol production in the study area, amounting to 17 billion litres in 2000, has risen to 86 billion lighters in 2010 (Table 4). Most of the increase was realized in the USA, which is responsible for a production of 50 billion lighters in 2010. Brazil is the second largest producer with 28 billion lighters, followed by the EU and China. Increases have been relatively high in the China, the USA and EU.

Biodiesel production was raised from 0.8 to 15 billion lighters EU is the highest producer, followed ex aequo by Brazil and the USA. Indonesia, Malaysia, Mozambique or South Africa are not producing significant amounts of biofuels, although they may be important producers in their respective regions. Biofuel production in the study area (86 and 15 billion lighters of ethanol and biodiesel, respectively) represents 97% and 77% of the global total production level. This makes the countries included in the analysis a more than representative group of biofuel production.

Table 4 Biofuel production in the study area (billion litres)

| | Ethanol | | | Biodiesel | | |
|---|---|---|---|---|---|---|
| Region | 2000 | 2010 | Increase | 2000 | 2010 | Increase |
| Brazil | 9.7 | 27.6 | 17.9 | Neg. | 2.1 | 2.1 |
| USA | 6.1 | 49.5 | 43.4 | Neg. | 2.1 | 2.1 |
| EU | 1.5 | 6.4 | 4.9 | 0.8 | 10.3 | 9.5 |
| Indonesia and Malaysia | N.i. | N.i. | N.i. | Neg. | 0.2 | 0.2 |
| China | Neg. | 2.1 | 2.1 | Neg. | 0.4 | 0.4 |
| Mozambique | Neg. | 0.02 | 0.02 | Neg. | 0.05 | 0.05 |
| South Africa | Neg. | 0.02 | 0.02 | Neg. | 0.05 | 0.05 |
| All | 17.3 | 85.6 | 68.3 | 0.8 | 15.1 | 14.3 |

Note: Neg. = negligible; n.i. = not included in the analysis.

## Land use

Land used for biofuel expansion was calculated by dividing increased biofuel production presented in Table 4 by biomass to biofuel conversion rates taken from literature. Since 2000, biofuel expansion in the study area has claimed an additional 25 million ha of crop land (Table 5). As 11 million ha is allocated to co-products, net biofuel expansion amounts to 14 million ha. Over 85% of this is located in the USA, where increased biofuel production has occupied over five million ha, the EU and Brazil.

Co-product generation is relatively high in the USA and EU. Main crops used to produce biofuels (corn, wheat, soy bean and rape), are dominant feed crops whose nutritive characteristics have long been known. Low co-product ratio in Brazil is explained by the high share of sugar cane, whose residues are mostly used in the production of biofuels or electricity (co-generation). Vinasse is recycled and used as fertilizer.

Since 2000, countries of the study area have seen a net decline in agricultural area with nine million ha. Loss of agricultural area in the USA, EU, China and South Africa amounted to 31 million ha, which is mostly compensated by expansion of agricultural land in Brazil (plus 12 million ha), Indonesia/Malaysia (plus nine million ha) and Mozambique. Net global loss of agricultural area amounted to 48 million ha. In many cases, loss of agricultural area has been much larger than net expansion of biofuel area. This was the case in the EU, China and South Africa. Only in the USA, biofuel expansion is the dominant cause of agricultural land use loss.

Table 5 Net changes in land availability (mln ha)

| Region | Increased land requirement | Associated with co-products | Net biofuel area increase | Changes in agricultural area | Extra harvested area due to increased MCI | Change in NHA |
|---|---|---|---|---|---|---|
| Brazil | 4.9 | 1.8 | 3.1 | 12.0 | 4.9 | 13.8 |
| USA | 11.0 | 5.9 | 5.1 | -3.5 | 10.9 | 2.3 |
| EU | 6.6 | 3.2 | 3.4 | -11.5 | 3.6 | -11.2 |
| Indonesia and Malaysia | 0.02 | 0.01 | 0.01 | 8.9 | 2.0 | 10.9 |
| China | 2.2 | 0.4 | 1.8 | -13.4 | 20.3 | 5.1 |
| Mozambique | 0.13 | 0.03 | 0.1 | 1.3 | 0.9 | 2.0 |
| South Africa | 0.12 | 0.04 | 0.1 | -2.7 | -1.2 | -4.0 |
| Study area | 24.9 | 11.4 | 13.5 | -9.0 | 41.5 | 19.0 |
| Global total | | | | -47.8 | 91.5 | |

Note: Neg. = negligible; n.i. = not included in the analysis.

Increasing the cropping frequency on arable land – reflected by an increase of the Multiple Cropping Index (MCI) – allows farmers to increase the harvested area on shrinking agricultural areas. This has facilitated additional crop harvests equivalent of 42 million ha. More than half of this was realized in China, where government policy has been oriented towards improving (maintaining) food production capacity. MCI also added considerable harvested areas in the USA, Brazil, the EU, Indonesia and Malaysia.

The role of MCI of improving agricultural output since 2000 can hardly be overestimated. Global increases, equivalent to 92 million ha of harvested crops, has been more than sufficient to compensate for losses of agricultural area.

Improvement of MCI in all but one cases is more than sufficient to compensate for expansion of biofuel area: this is the case in Brazil (where MCI generated five million ha while biofuels claimed three million ha – a positive balance of nearly two million ha), the USA (11 vs. five million ha), EU (0.2 million ha balance), Indonesia/Malaysia (plus two million ha), China (19 million ha) and Mozambique (0.8 million ha). South Africa, which noted a decline of MCI, is the exception to the rule of increased harvesting intensity.

The combined effect of biofuel expansion, changes in agricultural area and improvement of MCI generally is positive. Together, countries included in the study increased harvested area for non-biofuel purposes of 19 million ha. This increase allowed improved availability of crop production for traditional food, feed and fibre (FFF) markets. Net FFF area increased in most of the cases. It did , however, decline in the EU and in South Africa.

# 4. DISCUSSION

Following changes in biofuel policies in the course of the first decade of the 21st century, a strong expansion in biofuel production was observed in the USA, the EU, China and many other countries. The 34 countries of the study area realized an increase in ethanol production of 68 billion litre and 14 billion litre of biodiesel in 2010 as compared to 2000.

These increases, however, were not sufficient to fully satisfy policy objectives in the USA and EU. China, Indonesia and Malaysia have adjusted policies in response to substantial consumption of food cereals and high palm oil prices, respectively. For the near future, further expansion of biofuel production is expected especially in the USA, Brazil, Argentina and EU. Smaller, but significant, development may be expected elsewhere.

Land devoted to biofuel production was calculated at 32 million ha in 2010, an increase of 25 million ha as compared to 2000. Of this increase, 11 million ha is allocated to co-products. This means that nearly half of the increase in biofuel area in fact is used to generate crop biomass for the livestock feed market.

Clearly, ignoring co-product generation in early biofuel impact exercises has lead to an overestimation of land requirements, in most cases with 40 percent or more. The contribution of feed co-products is relatively high in the USA, China and the EU due to the large share of cereals with high feed yields. It is low in Brazil where ethanol production is dominated by sugar cane which generates no feed co-products. Co-generation from cane fibres has not been included in the calculations.

Biomass used for biofuel production, calculated from FAO statistics, amounts to 527 million ton in 2010. This is an increase of 334 million ton, of which 80 million ton is for co-product generation. Biofuel expansion therefore required 254 million ton of crops. Area expansion, amounting to 25 million ha (including co-products), has been relatively stronger due to a shift from high yielding (ton per ha) sugar cane to cereals like corn and wheat and to oil crops like soy bean and rapeseed all which have much lower yields than sugar cane. Implications for land use will, however, also depend on the role of yield improvement.

In literature, different assumptions on yield improvement can be found. For US corn, for example, Searchinger et al. (2008) assumed a maximum of 20% yield improvement in 30 years. Others have suggested that a considerable share of corn used in biofuels in the USA could be generated by yield improvements (Gallagher, 2010).

One should be extremely careful comparing crop yields as these tend to show large year-to-year variations, but corn yields calculated from FAOSTAT data in the USA suggest that a significant part of these yield improvements already have taken place between 2000 and 2010. Indicative yield improvements (3-yr averages) during this period of sugar cane in Brazil and wheat in the EU have been 17% and 11% respectively.

The changes in land use that were reported are most revealing. The loss of agricultural area due to urbanization etc. in industrial countries (USA, EU, South Africa) exceeds biofuel expansion by two times (31 vs. 14 million ha). Expansion of agricultural area in other countries (Brazil, Indonesia, Malaysia, and Mozambique) amounted to 22 million ha. Changes in intensification of arable cropping are even larger.

On a global scale, the Multiple Cropping Index increased with 7 percent in a period of ten year. This may not seem high, but as it applies to 1.4 billion ha, the implications are enormous. In the study area, improvement of cropping intensity has been variable. It rose with 14 per cent in China, 10 per cent in Brazil and Mozambique and four percent in the EU. Other countries take an intermediate position.

For the entire study area, 42 million ha of crop harvested area has been generated. Consequently, reduction of unutilised arable land (CRP in the USA, set-aside in the EU plus fallow) and increase of double-cropping has been sufficient to generate nearly three times the amount of biofuel land expansion. Both fallow reduction and double-cropping seem to have been largely ignored in the debate so far which is a serious omission.

Improving MCI was identified as a major source of harvested area by OECD-FAO (2009), but the consequences for land availability vis-à-vis future biofuel expansion were not assessed. Bruinsma (2009) focused mainly on yield improvement. Economic models used in evaluation of biofuel policies appear to have neglected the potential contribution of MCI.

For the future, MCI may be expected to show further increases. The implications will, however, depend on crops and farming systems. Tropical regions have a larger potential for double-cropping (provided sufficient water is available). Cereals and pulses, having relatively short growing cycles, provide good perspectives. Sugar cane, occupying land year round, has limited potential for increased MCI. Climate change may, however, also offer new opportunities for temperate regions, e.g. when temperatures in spring allow early harvesting of winter cereals (Nafziger, 2008).

The approach that was followed has a number of advantages. Calculating full biomass balances allowed the assessment of biofuel feedstocks available for animal feed and – consequently – give a realistic assessment of the amount of feedstocks claimed for biofuel production. Claims by biofuel production on biomass and land resources were calculated with local data, thus providing a realistic view on cultivation practices, crop rotations, yields, and conversion efficiencies.

The use of full land balances has put land demand for biofuels in perspective, integrating many processes which affect land requirement and changes in land use. Limitations to the approach are related to the large number of data that are needed. Data on crop rotations and cultivation practices often have a local nature which makes it difficult to obtain a more generic picture at the national level. Data on double-cropping and biomass to biofuel conversion are extremely difficult to obtain. Calculations, finally, have been restricted to major biofuel feedstocks.

Notwithstanding these limitations, the implications of the findings are large. The impact of the increases in cropping intensity can hardly be overestimated. On the one hand, observed MCI improvement since 2000 demonstrates that projected biofuel crop areas (estimated up to 50 million ha in 2050) can easily be compensated. In one decade, enhanced cropping intensity generated as much as 92 million ha of harvested crops worldwide. This is surprisingly high, and the consequences are clear.

While biofuel production may occupy a significant amount of crop land in the future, there are strong drivers of crop area expansion which may be able to generate similar – or larger – additional harvested areas in biofuel countries. Thus, there is no reason to expect that biofuel expansion will lead to reduction of area of food/feed production. For the first decade of the 21st century, net harvested area for traditional (non-biofuels) biomass markets in the study area increased with 19 million ha.

The outcomes of this study will have to be considered while debating issues related to biofuel production. Questions can be raised on current insights in land use change caused by biofuels. Our paper clearly shows that biofuel expansion has not been the major factor determining land use change. Loss of arable land due to urbanization etc. has claimed over two times more land. This loss is probably permanent, which is not the case for biofuel production. Increased intensity of arable land use, further, has generated more than sufficient harvested area to fully compensate biofuel expansion. This makes claims of land use changes caused by biofuel expansion (as caused by biofuel policies) less convincing.

Consider, for example, projected land use change caused by EU biofuel policies. In 2020, an additional area of 0.5 million ha has been projected to be devoted to biofuels in Brazil (Al Riffai et al., 2012). Only 15% of this is associated with deforestation. These are small figures, which suggest that the role of biofuel expansion as major driving force for deforestation in Brazil needs to be reconsidered (26 million ha of forest was lost since 2000).

Projected land use change due to EU policies should also be compared to the increase of MCI observed in Brazil, generating almost (five million ha or) ten times the amount lost to EU biofuel exports in just one decade. In the light of these figures it is hard to imagine that biofuel policies are major sources of land use change or deforestation.

The food versus fuel debate, further, needs to be enriched. While biofuel expansion in the study area has claimed 14 million ha of arable land, this area is more than compensated by increased cropping intensity. FAOSTAT data clearly show that harvested area for food/feed markets has increased. They also show that biomass availability for food and feed applications has gone up. Further, not biofuel expansion but loss of agricultural land due to urbanization etc. is the major threat to land (biomass) availability. All this needs to be considered in the debate.

The outcomes of this study show that it is essential for policy impact analyses to use statistical data to check model projections. Further, the analysis should be based on full – and not partial – biomass and land balances. Initial restrictions in model applications, ignoring co-product generation, seem to have given strongly distorted conclusions. Excluding double cropping or cropping intensity in biofuel policy analysis has been another major restriction which has had a major impact on the outcome.

It is suggested, therefore, to incorporate local and national data on crop cultivation (e.g. crop rotations) in assessment studies of biofuel policies.

Keeney and Hertel (2008) indicated that forecasting environmental impacts of biofuel policies requires both careful model formulation as well as sufficient empirical knowledge on supply and demand. Currently, only a few key parameters (e.g. yield elasticity, acreage response elasticity) determine the outcome of land use change modelling studies.

It should be checked to what extent models that have been used (e.g. GTAP, IMPACT) correctly predicted adjustments in crop production and land use practices. Essential elements that may be lacking include changes in fallow and double-cropping, accelerations in yield improvement, and loss of agricultural land due to urbanization etc.

Special attention may be given to cropping intensity (this study), as well non-biofuel crop yield improvement (Golub and Hertel, 2012). In this process, predicted changes in crop production and land use should be critically evaluated. Keeney and Hertel (2008), for example, predicted an increase of crop production to coincide with a reduction of forest and pasture areas in the USA, EU and Latin America. FAO statistics have shown that, so far, forest area in the USA and EU has increased while grassland area remained constant in the USA and in Brazil.

The outcome of this process on assumed GHG emission reduction from biofuel production is potentially very large. Very high assessments of carbon releases due to indirect land use changes (e.g. presented by Searchinger et al., 2008; or IFPRI - Al Riffai et al., 2012) have been used to underpin adjustments in biofuel policies in the EU.

This paper shows that a careful reconsideration of the generally assumed view that biofuels are important causes of indirect land use change is called for. This should be done using observed – rather than projected – data.

# 5. CONCLUSION

This paper addressed the impact of increased biofuels production on land use in major biofuel producing countries using full land balances based on land and crop statistics. Biofuel expansion is often considered a major threat for biomass availability for food and feed production and an important source of land use change.

FAO statistics on crop production and land use in the period 2000 to 2010 show, however, that the impact of biofuel expansion on land use has been limited. An increase of 14 million ha was noted in 34 major biofuel producing nations over a period of a decade. During the same period, increased cropping intensity generated over 42 million ha of extra crop land – three times the biofuel expansion. Further, an area of 31 million ha of agricultural area was lost (amongst other due to urbanization) in the USA, the EU, China and South Africa.

Consequently, there are strong drivers for expansion of land availability for traditional food and feed markets which has led to increased food and feed crop area. With exception of the USA, biofuel expansion has not made up more than a quart of the total loss of agricultural land.

This information should be considered in discussions on food vs. fuel debate and land use change (iLUC) caused by biofuel policies. Existing frameworks need to be reconsidered. Biofuels can, for example, not be identified as the most important or single global cause of land use change. Other sources have caused more (and more permanent) loss of agricultural area. This includes process of urbanization, infrastructure development, but also tourism and even nature development (an additional 8 million ha of forest have been installed in the USA and EU since 2000). Projected changes in land use caused by biofuel policies are very small in comparison to other changes.

It is recommended that models used to evaluate biofuel policies are adjusted. They should incorporate more and better information on (changes in) land use and local cropping patterns, as well as differences in current and potential productivities in different agro-ecologies and farming systems. Dynamics of crop production systems need to be covered better.

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