Modeling and Analysis

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Analyzing the effect of biofuel expansion on land use in major producing countries: evidence of increased multiple cropping

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Abstract: Estimates on impacts of biofuel production often use models with limited ability to incorporate changes in land use, notably cropping intensity. This review studies biofuel expansion between 2000 and 2010 in Brazil, the USA, Indonesia, Malaysia, China, Mozambique, South Africa plus 27 EU member states. In 2010, these countries produced 86 billion litres of ethanol and 15 billion litres of biodiesel. Land use increased by 25 Mha, of which 11 Mha is associated with co-products, i.e. by-products of biofuel production processes used as animal feed. In the decade up to 2010, agricultural land decreased by 9 Mha overall. It expanded by 22 Mha in Brazil, Indonesia, Malaysia, and Mozambique, some 31 Mha was lost in the USA, the EU, and South Africa due to urbanization, expansion of infrastructure, conversion into nature, and land abandonment. Increases in cropping intensity accounted for 42 Mha of additional harvested area. Together with increased co-product availability for animal feed, this was sufficient to increase the net harvested area (NHA, crop area harvested for food, feed, and fiber markets) in the study countries by 19 Mha. Thus, despite substantial expansion of biofuel production, more land has become available for non-fuel applications. Biofuel crop areas and NHA increased in most countries including the USA and Brazil. It is concluded that biofuel expansion in 2000–2010 is not associated with a decline in the NHA available for food crop production. The increases in multiple cropping have often been overlooked and should be considered more fully in calculations of (indirect) land-use change (iLUC). © 2013 Society of Chemical Industry and John Wiley & Sons, Ltd

Keywords: biofuels; land use change; iLUC; food vs. fuel; ethanol; biodiesel; co-products; Brazil; USA; EU; China.

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Introduction

Increased biofuel production has led to criticism and concerns about food availability while it is feared that rising demand for cropland will lead to deforestation, grassland conversion and increased Greenhouse Gas (GHG) emissions from these land use changes. The main criticism is based on expected impacts of biofuel production following the introduction of dedicated biofuel targets and policies.[1–3]

Commonly used economic models in biofuel policy evaluation include multimarket partial equilibrium models such as the FAPRI-CARD, ESIM, and IMPACT model, and computable general equilibrium (CGE) models such as the Global Trade Analysis Project (GTAP), LEITAP and the Modeling 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.[4–6] This has consequences for the way the models 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)[1,7] while second-generation biofuel production technology, at least in early applications, was not included.[4]

Other restrictions include limited ability to adjust to accelerations in yield improvement[7] or to changes in crop rotation.[9] Most 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 limited extent,[8] which is considered a significant drawback of model results.[7] Changes in programs offering farmers compensation for not cultivating arable land (Conservation Reserve Program (CRP) in the USA and Set-Aside in the EU), for example, were often not adequately represented. Further, models do not fully incorporate impacts of trade policies (e.g. preferential biofuel imports[8]), crop tillage,[10] or agro-ecological conditions in crop production areas.

While the exact consequences of these limitations remain unclear, there is a 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 the Food and Agriculture Organization (FAO) suggest that increasing cropping intensity will be an important source of additional crop biomass. According to Nachtergaele *et al.*,[11] cropping intensity is projected to increase by a total of 4% in developing countries between 2006 and 2050. For developed countries, however, the forecast increase is 7%. Global average is projected to increase by 6%.

Central to 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. At the core is the way increased biomass requirements are to be met by area expansion, yield improvement or by increased cropping intensity. Bruinsma[12] estimated that 80% of the projected growth in crop production in developing countries up to 2050 would come from intensification in the form of yield increases (71%) and higher cropping intensities (8%). Higher shares are projected in land-scarce regions such as South Asia and the Near East/North Africa where increases in yield would need to compensate for the expected 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 (albeit possibly temporary) 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 might have to be moderated. Especially the projected increases in cropping intensity may be on the low side. Using data for 1962–2007, OECD-FAO[13] for example calculated that half of the realized increases in the harvested area were attributable to increased cropping intensity (the other half have been related to area expansion).

More recently, reduction of (fodder and) CRP area and increased double-cropping have been reported for the USA.[14] For example, about 16% of 2008 corn and soybean farms had brought new acreage into production since 2006. This new, formerly uncultivated, land accounted for approximately 30% of the reported farm's expansion in total harvested acreage. Most acreage conversion came from uncultivated hay. Some 15% of corn and soybean farms reported a harvested acreage (summing up all crops) exceeding their arable area in 2008, implying an increase in double-cropping. These farms reported greater expansion in harvested biofuel crop acreage than other farms, suggesting double-cropping is a quick and effective strategy to generate additional biofuel crop biomass.

Given the above limitations, economic model impact assessments of biofuel policies should be considered with care. Consequences of the limitations on the modeling outcome are difficult to assess but they may be considerable. The introduction of co-products in a GTAP evaluation of US and EU biofuel policies, for example, was

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assessed to reduce the need for land conversion with 27%.[6] According to Croezen and Brouwer,[15] scenarios including second-generation biofuel technologies resulted in land-use requirements that were 50% lower as compared to scenarios which did not include lignocellulosic biofuel conversion technologies.

In summary, the use of estimates of biofuel scenarios based on incomplete information could generate misleading estimates. Another risk is the inadequate input use, which 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.

With a view to improving the accuracy of data for evaluations of biofuel policy impacts, this paper assesses data from different sources of biomass production of eight major biofuel producers. We analyze biofuels and feedstock 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. 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: the crop area that is harvested in a country or region in a given year. This differs from the amount of arable land, as land may be harvested several times, while fallow land is not harvested at all.
- Agricultural area 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: the ratio of harvested crop area to the amount of arable land.*

The relation between these concepts is the following equation:

- Harvested area = arable area * cropping intensity (1)

In our analysis, we estimate land and biomass balances. Based on the volume of biofuels produced, the equivalent amount of biomass and the required area of land is calculated. These estimates are based on detailed material collected and analyzed for a book on biofuel crop production systems currently in preparation. The review is organized as follows. First, it describes available land resources in the study countries. Next, it presents biofuel production in 2010 which is compared to that in 2000. Implications of biofuel expansion for land use are given, as are other changes in land use that have been observed. This is followed by a discussion and some conclusions.

Land resources

An overview of land cover and land use in the study countries 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 countries total). Agricultural area is high in China, the USA and (on a relative scale) the EU, Mozambique, and South Africa. Most arable land is found in the USA, China, and the EU, permanent grasslands being important in China (hosting more than one-third of the study area grassland), the USA, and Brazil. We calculated cropping intensity, expressed as the 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,[16] but can be calculated for temperate regions as well.[12] MCI in the study countries varies between 0.53 in South Africa, 1.45 in China. It is around 0.8 in Brazil, the USA, and the EU.

Biofuel production

Sugarcane 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 soybean (Brazil, USA), rapeseed (EU), and oil palm (Indonesia and Malaysia). There are other feedstocks of minor importance, such as castor beans in Brazil, sunflower in the EU and Jatropha in Mozambique, but these are not included in the analysis.

Large differences exist in the way fields are prepared for biofuel production. There are a number of practices which

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

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).[18]

Table 2. Biofuel production chains included in the analysis.

Region	Feedstock	Biofuel	Field preparation	Input use
Brazil	Sugarcane	Ethanol	Pre-harvest burning is phased out	Moderately low
Brazil	Soybean	Biodiesel	Mostly no-till	Low
USA	Corn	Ethanol	Mostly plowed	High
USA	Soybean	Biodiesel	Half under no-till	Moderately low
EU	Wheat	Ethanol	Plowing	High
EU	Rapeseed	Biodiesel	Plowing	High
EU	Sugarbeet	Ethanol	Plowing	Moderately high
Indonesia and Malaysia	Palm oil	Biodiesel	Pre-harvest burning	Moderately low
China	Corn	Ethanol	Plowing	Very high
China	Wheat	Ethanol	Plowing	Very high
Mozambique	Sugarcane	Ethanol	Pre-harvest burning	Moderately high
South Africa	Sugarcane	Ethanol	Pre-harvest burning	High

determine the performance of the biofuel production chain including pre-harvest burning of sugarcane leaves and plowing for arable crops. Burning leaves of sugarcane is common practice before manual harvesting in order to avoid injuries to laborers. This causes a considerable loss of leaf material and soil organic matter, while emissions of particulate matter cause a threat to the laborers' lungs. This practice is gradually being phased out in Brazil where mechanical green harvesting is becoming more common. Plowing arable fields, causing loss of soil carbon, is common in the EU and in China, but less so in the Midwest of the USA and soybean cultivation in Brazil, who have adopted conservation agriculture. Use of fertilizers and agro-chemicals is highly variable. Input use in feedstock production is low to moderately low in Brazil and in the USA (corn), Indonesia, Malaysia and Southern Africa. It is high in the production of cereals (USA, EU, and China) and rapeseed. Sugarbeet holds an intermediate position.

The main output data are presented in Table 3. Crop yield is high for sugarcane (Brazil, South Africa), sugarbeet, 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 soybean yields are modest. Ethanol yields are highest for sugarbeet, and sugarcane (Brazil). Highest biodiesel yields were observed for oil palm (Indonesia, Malaysia). 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 soybean. 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 equivalent

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Table 3. Crop, biofuel and coproduct yields.

Region	Feedstock	Crop yield (ton/ha)	Biofuel yield (l/ha)	Biofuel yield (GJ/ha)	Co-product yield (ton/ha)
Brazil	Sugarcane	79.5	7200	152	–
Brazil	Soybean	2.8	600	18	1.8
USA	Corn	9.9	3800	80	4.2
USA	Soybean	2.8	600	18	1.8
EU	Wheat	5.1	1700	37	2.7
EU	Rapeseed	3.1	1300	43	1.7
EU	Sugarbeet	79.1	7900	168	4.0
Indonesia and Malaysia	Palm oil	18.4	4200	90	4.2
China	Corn	5.5	2200	46	2.9
China	Wheat	4.7	1700	36	2.5
Mozambique	Sugarcane	13.1	1100	23	–
South Africa	Sugarcane	60.0	5000	107	–

Source: crop yields calculated from FAOSTAT (2013),[18] biofuel and co-product yields calculated from literature.

which allows better comparison. Co-product yields are high for corn (USA), oil palm, and sugarbeet. Yields are low for rapeseed and soybean, while no co-products for the food or feed market are generated by sugarcane-ethanol.

Ethanol production in the study countries, amounting to 17 billion litres in 2000, rose to 86 billion litres in 2010 (Table 4). Most of the increase was realized in the USA, which was responsible for a production of 50 billion litres in 2010. Brazil is the second-largest producer with 28 billion litres, followed by the EU and China. Increases have been relatively high in China, the USA, and the EU. Biodiesel production rose from 0.8 to 15 billion litres. The EU is the highest producer, followed 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 countries (86 and 15 billion litres of ethanol and biodiesel, respectively) represents 97% and 77% of the global total production level. Thus, conclusions of global significance can be drawn from the analysis of the study countries.

Table 4. Biofuel production in the study countries (billion l).

	Ethanol			Biodiesel		
	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

Notes: N.i. = not included; Neg. = negligible.

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 countries has claimed an additional 25 million ha of cropland (Table 5). As 11 million ha is allocated to co-products, net biofuel expansion amounts to 14 million ha. Over 85% of area expansion occurred in the USA, where increased biofuel production has occupied over 5 million ha, and in the the EU and Brazil. Co-product generation is relatively high in the USA and the EU. The main crops used to produce biofuels (corn, wheat, soybean, 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 sugarcane, 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 by 9 million ha. Loss of agricultural area in the USA, the EU, China, and South Africa amounted to 31 million ha, which is mostly compensated

Table 5. Net changes in land availability.

	Increased land requirement (mln ha)	Associated with co-products (mln ha)	Net biofuel area increase (mln ha)	Changes in agricultural area (mln ha)	Extra harvested area due to increased MCI (mln ha)	Change in NHA (mln ha)
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, 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
All	24.9	11.4	13.5	–9.0	41.5	19.0
Global total				–47.8	91.5	

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. It is only in the USA that biofuel expansion is the dominant cause of agricultural land use loss.

Increasing the cropping frequency on arable land – reflected by an increase of the MCI – allows farmers to increase the harvested area on shrinking agricultural areas. This has facilitated *additional* crop harvests equivalent to 42 million ha. More than half of this expansion was realized in China, where government policy has been oriented toward improving (maintaining) food production capacity. MCI also added considerable harvested areas in the USA, Brazil, the EU, Indonesia, and Malaysia. The role of MCI in improving agricultural output since 2000 can hardly be overemphasized. Global increases, equivalent to 92 million ha of harvested crops, have been more than sufficient to compensate for losses of agricultural area.

Improvement of MCI in all but one case is more than sufficient to compensate for expansion of biofuel area: this is the case in Brazil (where MCI generated 5 million ha while biofuels required 3 million ha – a positive balance of nearly 2 million ha), the USA (11 *vs.* 5 million ha), EU (0.2 million ha balance), Indonesia/Malaysia (plus 2 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 cropping 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 fiber (FFF) markets. Net FFF area increased in most of the cases, except for the EU and South Africa.

Discussion

Following changes in biofuel policies in the course of the first decade of the twenty-first century, a strong expansion in biofuel production was observed in the USA, the EU, China, and many other countries. The 34 study countries realized an increase in ethanol production of 68 billion litres and 14 billion litres of biodiesel in 2010 as compared to 2000. These increases, however, were not sufficient to fully satisfy biofuel policy objectives in the USA and the 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 the 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 can be allocated, using standard conversion rates, 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 assessments has led to an overestimation of land requirements, in most cases by 40% 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 sugarcane which generates no

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feed co-products. However, it should be noted that the co-generation of electricity from sugar cane residues has not been included in the calculations.

Biomass used for biofuel production, calculated from biofuel literature and FAO statistics, amounted to 527 million ton in 2010. This is an increase of 334 million ton, of which 80 million tons is for co-product generation. Biofuel expansion therefore required 254 million tons 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) sugarcane to cereals like corn and wheat and to oil crops like soybean and rapeseed all which have much lower yields than sugarcane. 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.*[19] 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.[20] One should be extremely careful comparing crop yields as these tend to show large year-to-year variations. However, US corn yields calculated from FAOSTAT data suggest that a significant part of these yield improvements already has taken place between 2000 and 2010. Indicative yield improvements (3-year averages) during this period of sugarcane 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) is two times larger than biofuel expansion (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 MCI increased by 7% in a period of ten years. This may not seem high, but as it applies to an area of 1.4 billion ha, the implications are enormous. In the study area, improvement of cropping intensity has been variable. It rose by 14% in China, 10% in Brazil and Mozambique, and 4% 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, the reduction of unutilized arable land (CRP in the USA, set-aside in the EU plus fallow) and an increase in 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. Improved MCI was identified as a major source of increased harvested area by OECD-FAO,[12] but the consequences for land availability vis-à-vis future biofuel expansion tend to have been overlooked. Bruinsma[11] focused mainly on yield improvement. Economic models used in evaluation of biofuel policies appear to have neglected the potential contribution of MCI.

In the future, MCI may be expected to show further increases. The magnitudes 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. Sugarcane, occupying land year round, has limited potential for increased MCI. Climate change may, however, also offer new opportunities for temperate regions, for example, when temperatures in spring allow early harvesting of winter cereals.[17]

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 – gives a realistic assessment of the amount of feedstocks required for biofuel production. Requirements of biofuel production for biomass and land resources were calculated with local data, thus incorporating a realistic assumption of 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 of 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 while the exact relation between biofuel production and increased MCI needs to be investigated. Calculations, finally, have been restricted to major biofuel feedstocks.

Notwithstanding these limitations, the implications of the findings are substantial. The impact of the increases in cropping intensity can hardly be overemphasized. 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 extra 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 little reason to expect that biofuel expansion will lead to substantial reductions of area of food/feed production. For the first decade of the twenty-first century, net harvested area for traditional (non-biofuels) biomass markets in the study area increased by 19 million ha.

The outcomes of this study are relevant to the debates related to biofuel production. Our review clearly shows that biofuel expansion has not been the major factor causing land-use change. Loss of arable land due to urbanization, etc., has claimed over twice as much land. This loss is almost certainly permanent, which is not the case for biofuel production. Further, increased intensity of arable land use 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.[2] Only 15% of this is associated with deforestation. These are small figures, which suggest that the role of biofuel expansion as a 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 alone are the dominant source 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 for 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, it is not biofuel expansion but loss of agricultural land due to urbanization, etc., that 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 misleading conclusions. Excluding double-cropping or cropping intensity in biofuel policy analysis has been another limitation which has had a major impact on the results. 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[8] indicated that forecasting environmental impacts of biofuel policies requires both careful model formulation as well as sufficient empirical knowledge of supply and demand. Currently, only a few key parameters (e.g. yield elasticity, acreage response elasticity) determine the outcome of land-use change modeling studies. It should be checked to what extent popular analytical models correctly predicted adjustments in crop production and land-use practices. Essential elements that may have been lacking include changes in fallow and double-cropping, accelerations in yield improvement, and loss of agricultural land due to urbanization, infrasructure and industry.

Special attention is merited for cropping intensity, as well as non-biofuel crop yield improvement.[7] In this process, predicted changes in crop production and land use should be critically evaluated. Keeney and Hertel,[8] for example, predicted an increase of crop production to coincide with a reduction of forest and pasture areas in the USA, the EU, and Latin America. FAO statistics have shown that, during the last decade, forest area in the USA and EU has *increased* while grassland area remained constant in the USA and in Brazil.

The implication of this analysis for estimations of GHG emissions from biofuel production is potentially substantial. Very high assessments of carbon releases due to indirect land-use changes[2,18] have been used to underpin adjustments in biofuel policies in the EU. This review shows that a careful reconsideration of the generally assumed view that biofuels are important causes of indirect land use change is in place. Whereever feasible, this should be done using observed – rather than modeled – data.

Conclusion

This review 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. However, this analysis based on FAO statistics on crop production and land use in the period 2000 to 2010 shows 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 the exception of the USA, biofuel expansion has not made up more than a quarter of the total loss of agricultural land.

This information should be considered in discussions on food vs. fuel debate and land-use change caused by biofuel policies. Existing frameworks need to be reconsidered. For example, biofuels *cannot* be identified as the most important or single global cause of land-use change. Other drivers have caused more (and more permanent) loss of agricultural area including process of urbanization, infrastructure development, tourism and even conversion into nature (an additional 8 million ha of forest have been established in the USA and the EU since 2000). Observed changes in land use caused by biofuel policies are very small in comparison to other changes.

Models used to evaluate biofuel policies should be enriched by incorporating 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. Finally, the relation between increased multiple cropping and biofuel production should be further investigated.

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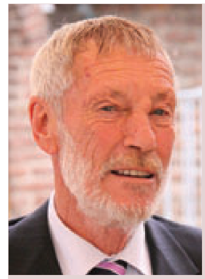

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