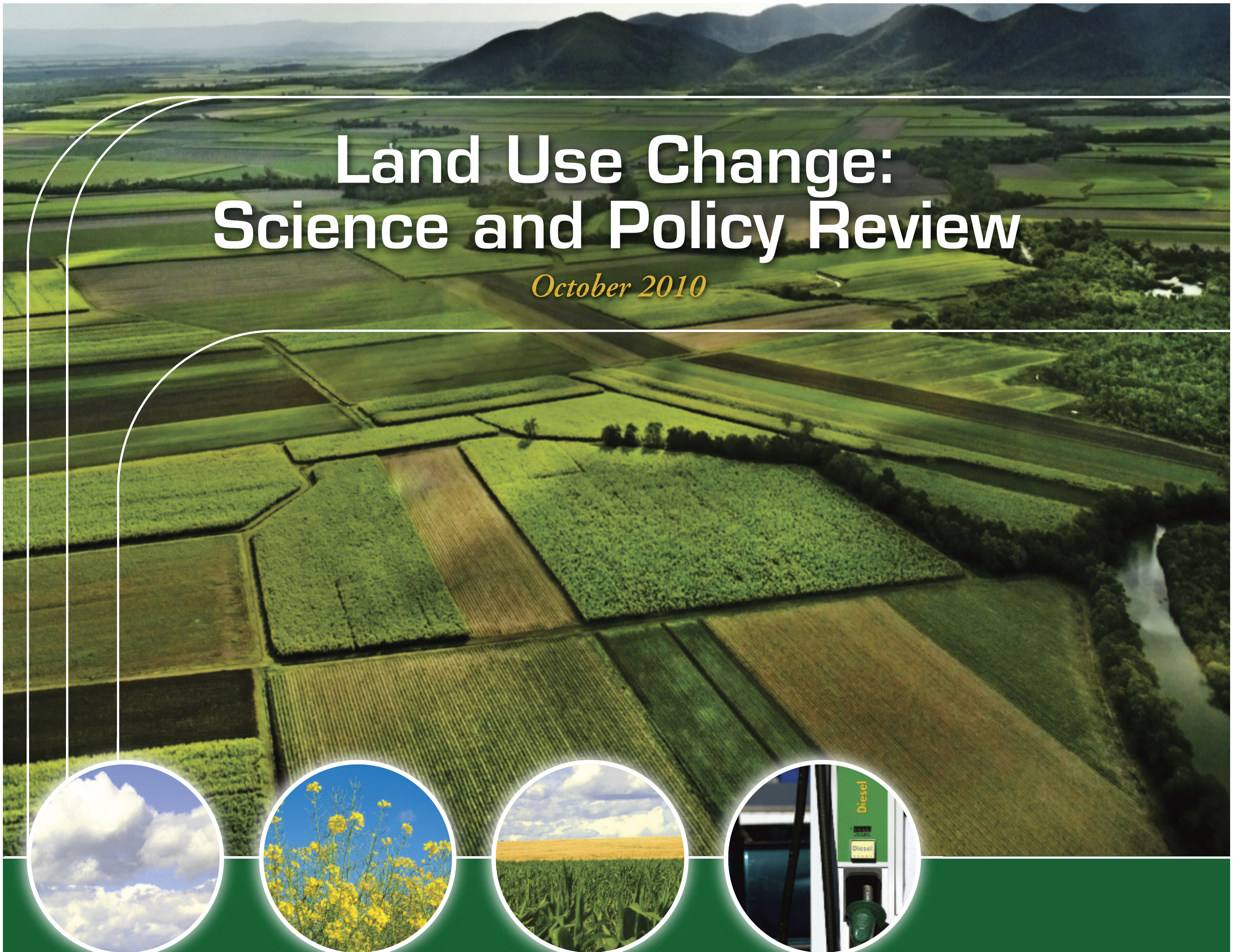

Land Use Change: Science and Policy Review

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I. EXECUTIVE SUMMARY

Never before has humanity had to think so carefully about how it uses land. Until recent times, there has been a widespread assumption that there are always new lands available, with no long term global consequences for exploiting them. This era has now ended. As the world's population and consequently, food and energy needs, increases, so does the pressure on land to meet these needs. With specific respect to biofuels, as production continues to grow in response to demand, the pressure to expand feedstock crop-growing areas continues to grow as well. This in turn leads to the possibility of land use changes.

It is the purpose of this paper to provide a concise review and summary of land use change (LUC) issues specifically as it relates to the increasing production and consumption of biofuels. This paper attempts to summarise, add insight and provide understanding of the complexities of these issues from a scientific and policy standpoint in a very brief manner.

This paper is not a scientific study and does not provide a comprehensive overview of all the mounting analyses that have been conducted in this area. It *does not* advocate a particular position be taken on the issue. In addition, this paper does not address other issues that have been raised in the context of the current discussions surrounding LUC though we acknowledge them here. For example, the question has been raised about properly allocating LUC to biofuels feedstock crops versus non-biofuels crops. Stakeholders have questioned why LUC should be addressed for biofuels and not other economic activities, including fossil fuels.

Rather, we have selected key studies and analyses that have been *peer reviewed* to present examples and highlight the biofuels LUC issues at hand. This paper has been peer reviewed by a diverse and select group of experts and we are most grateful to them for their time, feedback and assistance in developing this paper. For those readers interested in further study of biofuels LUC, a comprehensive bibliography of sources is available both at the back of this paper and further documentation can be found online through the Biofuels Information Exchange, located on the web at: http://biofuelexperts.ning.com/. A forum for discussion is available on the same site. As the current body of work on biofuels LUC expands, we invite authors to contribute their work there.

LUC is a complex process caused by the interaction of natural and social systems at different temporal and spatial scales (Rindfuss et al 2004) and large numbers of variables are required to be input; for example, landholders' experience, family structure, economic and technical resources and the socioeconomic context. LUC and LUC patterns are created by actors and they interact and collaborate in a variety of contexts (as individuals, families, communities, or corporations) (Robiglio et al 2003). LUC can be sub-divided into:

- Direct LUC (DLUC), which occurs *in situ* which results from a commercial decision as part of a specific supply chain for a specific product e.g. if a field is changed from growing wheat to oil seed rape, and
- Indirect LUC (ILUC), where other land is changed as a consequence of the direct change. For example, if less wheat is grown, other lands may be pressed into service to supply the shortfall. This could include LUC in another country or continent.

Figure 1 presents a diagrammatic view of DLUC and ILUC.

If there are unutilized agricultural lands available then ILUC may be mostly uncontroversial. Another uncontroversial option is to increase output on the same land by increasing crops yields and/or using lands in new ways (e.g. double-cropping, pasture intensification, etc.). The problem arises when other lands, including forest and savannah, are pressed into service which may result in increase in greenhouse gas (GHG) emissions, as well as ecosystem service losses. The

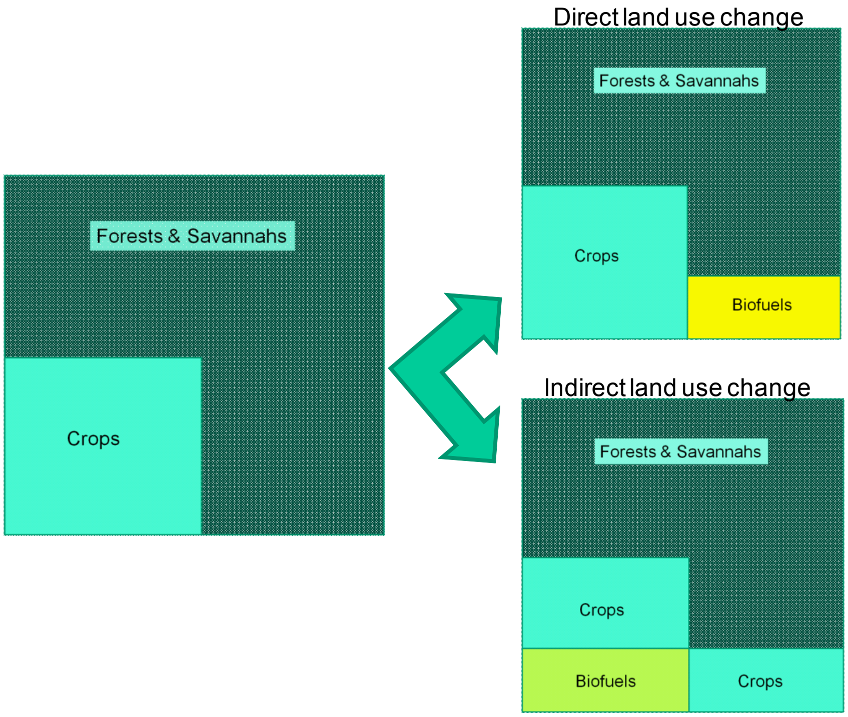

Figure 1: A diagrammatic explanation of ILUC (after Bauen and Howes in Woods, 2009).

concern about ILUC is fundamentally about the sheer scale of production that may be expected of the biofuel industry if it is to contribute significantly to reducing GHG.

Serious consideration of biofuel-related ILUC is a new phenomenon that was spurred by a paper by Searchinger et al (2008). Before that, LCAs of the "well-to-wheel" type were mostly attributional, i.e., consisting of a linear chain-like series of analytical steps, which did not carry out a consequential analysis, i.e., an assessment of nonlinear feedback-like effects. The Searchinger paper suggested that when including ILUC, the previously favourable GHG-saving crops of maize and cellulosic ethanol systems turned into net producers of GHG emissions. For those governments looking to biofuels as a strategy (among others) to reduce GHG emissions, the Searchinger paper raised serious concerns and new efforts were launched, particularly in the U.S. and Europe, to study biofuels LUC.

Introduction: Why Is Biofuels LUC Important?

Biofuels can be solid, liquid, or gaseous and are derived from biomass that can be combusted to produce heat or power. The current focus on biofuels is on those that can be used as transportation fuel in internal combustion engines. These include bioethanol from starch and sugar crops such as sugar cane, maize, sorghum, cassava, sweet potato; biodiesels from soy oil, palm oil, jatropha, pongamia, oil seed rape (canola), and waste oils; sources of lignin-cellulose such as switch grass, miscanthus, crop residues, tree prunings; algal fuels.

The majority of biofuels currently produced are from maize, sugar cane, soy oil, palm oil and oil seed rape. Lignin-cellulosic feedstocks must undergo further processing as they need to be first processed to sugars, either by heating with acid or converted using cellulase enzymes extracted from fungi. Algal biofuels, at an earlier developmental stage than cellulosics, may have promise since they could be grown on waste land, using waste carbon dioxide and waste water. Into the future, more investments in cellulosic and algal biofuels are expected (DBCCA 2009).

Biofuels feedstocks are highly diverse in their input requirements, alternative uses and climatic requirements and are grown in many different contexts globally. LCAs of different biofuel crops reveal large differences in yields, climatic requirements, energy balances, and water and carbon footprints. This review will focus on the production of agricultural crops or feedstocks suitable for bioethanol and biodiesel production because these compete with land, energy and water use for food production. Crops that can be used as biofuels are listed in Table 1, with the temperature and water requirements as well as their alternate food values. It should be noted that the figures in the table do not indicate optimal conditions, which may be more restricted.

Common name	Genus sp	biofuel type	max temp (°C)	min temp (°C)	max rainfall (mm/annum)	min rainfall (mm/annum)	protein value	edible oil value	edible carbohydrate
Oilseed rape	*Brassica napus*	D	40	6	1500	400		high	
Linseed	*Linum usitatissimum*	D	32	4	1300	250	medium		
Field mustard	*Sinapis alba*	D	27	7	1200	600			
Hemp	*Cannabis sativa*	D,S	28	5	1500	600			
Sunflower	*Helianthus annus*	D	39	15	1500	350		high	
Safflower	*Carthamus tintorius*	D	45	20	1300	400		high	
Castor	*Ricinus communis*	D	38	17	2000	500			
Olive	*Olea europea*	D	42	7	1300	200	low	high	
Groundnut	*Arachis hypogaea*	D	45	19	2000	450	high	high	
Sweet potato	*Ipomoea batatas*	E	45	17	1400	750	low		high
Cassava	*Manihot esculenta*	E	45	18	5000	500	low (leaves)		high
Barley	*Hordeum vulgare*	E,S	35	8	2000	250	high	high	high
Wheat	*Triticum aestivum*	E,S	32	11	1600	400	high	high	high
Oats	*Avena sativa*	E,S	25	6	1200	400	high	high	high
Rye	*Secale cereale*	E,S	32	11	1600	400	high	high	high
Potato	*Solanun tuberosum*	E	25	5	1500	500	medium		high
Sugar beet	*Beta vulgaris*	E	25	5	1500	500			high
Sugarcane	*Saccharum officinarun*	E	41	16	> 4000	1000			high
Sorghum	*Sorghum bicolor*	S,E	40	16	700	300	medium		high
Maize	*Zea mays*	S,E	40	9	2000	450	high		high
Reed canary grass	*Phalaris arundinacea*	S	38	1	2000	600			
Miscanthus	*Miscanthus spp.*	S	40	11	1500	600			
Eucalyptus	*Eucalyptus globulus*	S,D	36	6	2500	400			
Eucalyptus	*Eucalyptus camaldulensis*	S	36	7	2500	400			
Eucalyptus	*Eucalyptus grandis*	S	36	10	2500	400			
Jatropha	*Jatropha curcas*	D			2000	300			
African oil palm	*Elaeis guineensis*	D			3000	1000		high	
Pongamia	*Pongamia pinnata*	D			2000	300			

Table 1: Climatic requirements of crops that can be used as biofuels, noting values as foodstuffs (adapted from Tuck et al 2006) Key: D biodiesel; S solid biofuel; E, bioethanol.

As it pertains specifically to biofuels, an ILUC impact may be triggered when an increase in the demand for a crop-based biofuel begins to drive up prices for the necessary feedstock crop. This price increase causes farmers to devote a larger proportion of their cultivated acreage to that feedstock crop. Supplies of the displaced food and feed commodities subsequently decline, leading to higher prices for those commodities. In the past, many farmers have brought non-agricultural lands into production as a low-cost, high-benefit option to take advantage of higher commodity prices. These land use conversions release the carbon sequestered in soils and vegetation. The resulting carbon emissions constitute the ILUC impact of increased biofuel production. The land use conversions may also lead to a loss of ecosystem functions (e.g. biodiversity loss).

Based on the work done to date, and in particular the last two to three years, crop-based biofuels may contribute to some ILUC impacts. It is not clear what the magnitude of the impact actually is due to the complexity of the issues involved in assessing LUC generally and ILUC specifically. The tools for estimating and analysing ILUC impacts from biofuels are few and relatively new. And, the ranges of analyses conducted have produced varying results that are dependent on the assumptions used. Because of this evident complexity, it is worth noting some of the uncertainties, even though they are difficult to rank and quantify, and though some are more important than others:

- Much of the biofuel yields data is too inaccurate to calculate potential GHG effects, energy ratios and profits.
- Energy return on energy invested (EROI), a fundamental issue that has been insufficiently researched.
- Marginal and abandoned lands and the extent to which they can both be identified and rehabilitated. In fact, a common definition for marginal land does not currently exist (UNEP 2009).
- The extent to which any newly exploited land will be needed for food and the extent to which old land can be made more productive.
- The use of fertilizers and the optimal amount to use to minimize GHG releases, especially of nitrous oxide?
- Uncertainties about indirect effects. The Searchinger et al (2008) paper, despite numerous criticisms, revealed a potential flaw in our understanding of biofuels LUC and created new discussion about the importance of carefully considering biofuels DLUC and ILUC. As this may include cross-border effects, the complexities of estimating the effects are obvious.
- Soil carbon loss and sequestration, which depends greatly on the soils in question and how the land is farmed.
- Uncertainties in the science itself which has been outpaced by biofuels commercialization and scale-up over the last several years.
- A lack of a broad interdisciplinary approach to the subject. We understand for instance that LCA scientists had recognized the ILUC problem, but avoided it because of the problems of indeterminacy.

As the biofuels LUC issue has come to the fore, governments have pressed forward with setting and implementing mandatory biofuels programs. By end of 2010, approximately 39 countries have already implemented or are preparing to implement mandatory biofuels programs (Hart 2010) and most do not address biofuels LUC. Several governments have attempted to address LUC concerns in their biofuels programs, and have undertaken their own biofuels LUC analyses. They have ultimately concluded that the uncertainties involved should not prevent the development and implementation of policy that "factors in" biofuels ILUC.

Some governments have instituted an "ILUC penalty" or "ILUC factor" in their biofuels programs to account for the GHG emissions caused by ILUC of certain biofuels feedstocks. The introduction of an ILUC factor is meant to disincentivise the use of biofuels that may cause ILUC such as deforestation and allocate poorer GHG savings to these specific biofuels. Notably, some governments in structuring their biofuels programs have not implemented an "ILUC factor" but have set policies that address land use management and best agricultural practice for biofuels feedstock crops. Notably, many of these governments set these policies in conjunction with their biofuels programs and began to address issues related to LUC and biofuels *before* ILUC became a significant topic of discussion in the biofuels world.

As most of the biofuels policies that include an "ILUC factor" are currently being implemented, it is not clear at this time whether such factor will actually result in reducing ILUC. As an example, an ILUC factor that disfavours the use of palm oil as a biodiesel feedstock will not necessarily curtail the use of palm oil globally nor prevent the effects that have been associated to palm oil production growth (e.g. deforestation and biodiversity loss). The palm oil may not be used for biofuels production and consumption in the country with the ILUC factor policy in place, but could be used in a country that does not have such a policy. Moreover, such a policy would not likely curtail the use of palm oil as an important global food commodity.

Even so, the way in which land is allocated and used has become important as never before especially as population, income and consequently, food and energy demand, increases in the coming years. Note that while biofuels provided just 1.8% of the world's transport fuel in 2007 (UNEP 2009), this is expected to increase. According to the International Energy Agency (IEA), biofuels are projected to represent 9% of total transport fuel demand in 2030 (IEA 2009). Demand for petroleum products is expected to grow 1.6% per year through 2030 (Hart 2009). For many stakeholders and policymakers, this is why biofuels LUC is important to consider.

This paper is structured to address in brief the following topics:

- Land use implications of increased biofuel production
- Biofuels feedstock LCAs, energy balance and carbon footprint: how it relates to ILUC
- Additional environmental impacts related to ILUC
- Examples of select biofuels ILUC studies
- Regulatory and legislative actions undertaken to control ILUC from biofuels
- Other legislative and regulatory approaches that address ILUC
- ILUC and the emerging global biofuels market

The review concludes with some recommendations for next steps. These recommendations include more experimentation and modelling, which is already occurring; the establishment of standard methodologies to evaluate LUC from biofuels; quantifying available marginal land; and, establishing effective land use management and best agriculture practice policies for biofuels feedstock crops. We also suggest the development of a knowledge product or tool kit to help interested countries plan rationally for the future as they develop their biofuels programs.

2. LAND USE IMPLICATIONS OF INCREASED BIOFUEL PRODUCTION

Land use implications of increased biofuel production will depend on the crop grown and the context in which it is grown. With specific respect to biofuels, as production continues to grow in response to demand, the pressure to expand feedstock crop-growing areas continues to grow as well. This in turn leads to the possibility of LUC (both DLUC and ILUC) that in the biofuels context may include the following scenarios. Biofuel feedstock crops may be grown by:

- Bringing land that is not in agricultural use into production;
- Replacing existing food and fibre crops with biofuels feedstock crops;
- Cultivating degraded, abandoned land or land that is considered marginal;
- Intensifying land use without reducing crop production, including improving yields, technologies and integrating agriculture and livestock production.

None of these scenarios present easy solutions to the complex issue of LUC, even for the last two scenarios concerning new, non-food feedstocks and increasing yields on existing lands.

According to the Millennium Ecosystem Assessment (MEA 2005) nearly all of the world's suitable land is already under cultivation: "Although Africa and Latin America contain the majority of the world's remaining stock of potentially cultivatable lands, most of this currently supports rain forest and grassland savannas that provide many other ecosystem services and are crucial habitats for fauna and flora in natural ecosystems" (Bruinsma 2003).

Bringing Land That Is Not in Agricultural Use into Production

Campbell et al (2008) estimated the global potential for bioenergy on abandoned agriculture lands to be less than 8% of current primary energy demand. In the case of developing countries, Young (1999) concluded that the major assessments by international bodies and research organizations greatly over-estimate the extent of spare land, that is, land available for cultivation but presently uncultivated. The reasons given are:

- An over-estimation of the extent of cultivable land, through inclusion of hills and other uncultivable areas, that are individually small but of substantial total extent;
- An under-estimation of land already cultivated, statistics for which are demonstrably of great unreliability;
- Failure to take sufficient notice of the considerable requirements of other land uses, notably water supply, nature conservation, human settlements, and forest.

Making speculative adjustments to allow for each of these causes, Young found that a supposed land balance of 50% is reduced to one of between 3% and 25% of the present cultivable land. If this is correct, as an order of magnitude, then estimates of the total spare land in the developing world, and those for individual countries, should be reduced to half or less the values given by current estimates. We note, however, this is still a significant area.

The MEA notes that in many parts of North America, Europe, Japan and China, where productivity has grown faster than demand, land is increasingly being withdrawn from cultivation. On a global basis, there has been a steady decrease in area devoted to the major cereal crops, maize, rice and wheat, which account for the majority of calories in human diets, amounting to 2.4 million ha/year (Mha) since 1980. Kampman et al (2008) concur, estimating there is a large potential of idle land, especially in Russia, Ukraine and Kazakhstan where over the last 15 years almost 23 Mha of arable land became idle as a result of the breakup of the Soviet Union. Also in the United States (9 Mha) and Europe, idle land increased, aimed at limiting production or ensuring more sustainable land use.

Using an agro-ecological zones approach on the other hand, Fischer et al (2002) found that, at the global level, the Earth's land, climate, and biological resources are ample to meet food, pasture, fodder and fibre needs of future generations, in particular, for a world population of 9.3 billion, as projected in the United Nations medium variant for the year 2050. Despite this positive aggregate global picture though, they discovered reasons for profound concern in several regions and countries with limited land and water resources. However, Haugen (2010) strongly argues that these estimates, as well as the figures produced in a United Nations Food and Agriculture Organization (FAO) study (FAO, 1995) cannot be considered to be sufficiently accurate or ecologically justifiable to be applied as a basis for national strategies on land policies, either in agriculture or forestry.

Smeets et al (2007) estimated that between 730 Mha up to 3.6 Gha of agricultural land might become available in 2050, as a result of advancement of agricultural technology for food production, representing the technical potential to increase the efficiency of food production. But achieving the high side of this range would require a very drastic change of global agriculture, including for example landless animal production, genetically modified organisms and implementation of the best available technologies as well as very high levels of irrigation. In addition, there is uncertainty about future impacts of climate change and need for adaptation.

It is also worth noting that in recent years there already are increasing claims on tropical land for widespread biofuels plantations. In a review by FAO and the International Institute for Environment and Development, Cotula et al (2009) report that GEM Biofuels plc gained exclusive rights for 50 years over 453 Mha in Southern Madagascar to plant jatropha for biodiesel production whilst UK energy company CAMS Group have acquired a lease over 45 Mha of land in Tanzania for investments in sweet sorghum production for biofuels, whether these are "new" or existing agricultural lands is far from clear, nor who is presently occupying them or what ecosystem services they provide.

Replacing Existing Crops with Biofuels

If biofuel feedstock production becomes profitable for farmers they may switch their production from their current cropping regime. This potential scenario has raised international concern given that one billion people are still food-insecure (FAO 2009), global consumption of grains and oilseeds has exceeded production in seven out of the first eight years of the 21st century and the global stocks-to-use ratio has reduced from 30% to less than 15%, the lowest since 1970 (Trostle 2008).

However, the impact on food security would depend on the crop replaced. For example, coffee is grown on more than 11 Mha in the tropics, often by smallholder farmers (Waller et al 2007), coffee at the lower altitude margins will be replaced as climate change induced temperature rise continues and some of this could be turned over to biofuels, which could be a more sustainable alternative than beef pasture. Nevertheless, demand for coffee remains strong, and substitution would result in increasing levels of deforestation elsewhere, especially in Southeast Asia (e.g. Vietnam, Indonesia, Laos), which means that direct replacement of one crop by another still causes ILUC.

Cultivating Degraded, Abandoned Land or Land That Is Considered Marginal

It has been claimed that some biofuel crops can be grown on marginal land, under low rainfall conditions, otherwise unsuitable for arable production, and may have the potential to improve soil properties. Two examples often cited of this potential are *Pongamia pinnata,* native to India, and *Jatropha curcas,* native to Central America. Both are being investigated as potential biodiesel feedstocks. An appealing possibility for these biofuels feedstocks is that as hardy species, they might grow extensively on marginal or degraded land, with poor soils, low rainfall and with low agronomic inputs yet still yield enough to turn a profit from those picking it.

For example, much of the interest in jatropha stems from early work on the crop in Mali, India and a few other semi-arid regions, where the plant is common and habitually used for hedges to protect farm plots from intrusion by wildlife and cattle (Heller 1996; Francis et al 2005). However, some recent reports of the plant's ability to yield well in such conditions are disappointing (Brittaine and Lutaladio 2010). It appears that jatropha will survive in marginal conditions, but data are lacking to prove that it can be commercially successful under such conditions, particularly in large-scale plantations (Sanderson 2009).

In reality, jatropha may be more economically and environmentally viable in small-scale, community-based jatropha plantations, agroforestry systems with jatropha intercropping, and agro-silvo-pastoral systems (Achten et al 2010). Rural communities relying on fuel wood and expensive fossil fuel as energy source can substitute these with jatropha oil, which is easily and locally extractable with cheap technology (Achten et al 2008). The use of jatropha in low input systems for small-scale Jatropha oil production offers additional advantages, such as a diversification of the farmers' income sources, the reduction of soil erosion, the use of woody by-products and seed cakes as combustible or soil amendment and the use of jatropha hedges as living fences (Achten et al 2010).

Other feedstock crops suitable for bioethanol production that can be grown on marginal land include sweet cassava and sweet potato (Ziska et al 2009 and Ou et al 2010). These crops are grown in the U.S. and China and are also staple foods in many parts of the tropics. However, growing root crops on marginal land implies substantial soil disturbance, which leads to greater risk of soil erosion and release of soil carbon; modern zero tillage methods are preferable but not applicable in the case of root crops. Otherwise, perennial crops with established root systems and low soil disturbance may be more appropriate for marginal conditions where soils will often be poor and loose.

Intensifying Land Use without Reducing Crop Production

In many parts of the world, agricultural systems are extensive with low crop densities, no external inputs, fallows and low crop yields – this especially is the case for poor farmers. When population pressure increases and market access improves, these drivers motivate people to change their production systems (Boserup 1965; Binswanger and McIntire 1987), particularly when pressure is so high that there is no available uncultivated area to expand into or farmers do not have access to it because of ownership issues. Studies have shown that intensification is the outcome with a transition to greater resource use and higher yields (Demont et al 2007).

Methods include using innovations such as animal traction, integration of crops and livestock, improved cropping techniques, and use of external inputs (pesticides and fertilisers). Other techniques not reliant on purchased inputs include live mulch systems, i.e. rapidly growing herbaceous Leguminosae, which are regularly slashed, and grown in synchrony with the crop. The legumes fix nitrogen, maintain ground cover, control weeds and increase soil phosphorus availability (Lathwell 1990). Examples are different varieties of *Mucuna pruriens* subsp. *utilis, Pueraria phaseloides* and *Psophocarpus palustris*. Systems achieve increased nutrient recycling and use-efficiency through N-fixation, a deep-reaching root system and by producing biomass during the dry season. When such legumes are incorporated, fallow lengths can be reduced so yields also increase over time. In some cases, intensification has led to improved natural resource use fertility (Tiffen and Mortimore 1994).

Under these circumstances, biofuel production could, hypothetically, make complementary use of land, water and labour resources, increasing overall efficiency (Ziska et al 2009). For example, smallholder farmers could grow biofuel crops alongside food crops. This could increase cash flow, thus permitting input purchase, agricultural intensification and higher yields. The fuel, if locally processed, could create an affordable source of energy to semi-mechanize crop systems, reducing labour requirements in systems where labour is a limiting factor.

Thus intercropping biofuel crops with food crops or integrating perennial biofuels into existing cultivation systems might allow the development of fuel-food systems that increase resource use efficiency through spatial or temporal integration, but data on this are lacking. Work on intercropping systems can exploit a greater amount of limited growth factors when grown together than when apart, particularly if components have different architectures and / or resource demand peaks at different times in the growing season (Midmore 1993). Furthermore, if farmers intercrop a biofuel with a crop where they commonly apply fertilizers, or use land fertilized during the last cycle, the biofuel may inadvertently benefit through a residual fertilizer effect.

Problems lie in commercialization and this includes the difficulty of assessing quality of feedstock from so many small farms as well as the collection problem, especially for bulky raw material where considerable energy has to be expended to gather enough together to make it profitable to process. These and other problems (e.g. the implied shift to a more knowledge-intensive production mode) lie in the path of intensification for most smallholders. For plantations on the other hand, gains in productivity can be expected. There is a lack of data that quantify this gain, so further data collection is needed to assess the potential impact of land intensification on food crop vs. biofuel feedstock crop production.

Potentially the most likely biofuel feedstock for a low input system could be those derived from low-input high-diversity (LIHD) mixtures of native grassland perennials. According to Tilman et al (2006) such a system can provide more usable energy, greater GHG reductions, and less agrichemical pollution per hectare than can maize grain ethanol or soybean biodiesel. They found that high-diversity grasslands developed increasingly higher bioenergy yields that were 238% greater than monoculture yields after a decade. Moreover, LIHD biofuels can be produced on agriculturally degraded lands and thus need to neither displace food production nor cause loss of biodiversity via habitat destruction. An important caveat here is to determine and define the nature of degraded lands, since many lands of this type are still a wildlife refuge and in developing countries, used by nomadic pastoralists, for example.

In temperate areas, high input agriculture is the norm using inorganic fertilizer, pesticides, mechanisation and thus energy. Comprehensive statistics on comparative yields by crop are available from FAO. Bondeau et al (2007) assessed FAO data on country average maize grain yields, divided by climatic zone. They found that yields were highest in warm temperate areas, depending on input level, ranging from 3.5 Mg ha^{-1} in Turkey to approximately 9 Mg ha^{-1} in Greece. For cool temperate areas, yields presented were from 4 Mg ha^{-1} in China to more than 7.5 Mg ha^{-1} in Switzerland. Yields in tropical areas varied from 0.75 Mg ha^{-1} in the Democratic Republic of Congo to 2.5 Mg ha^{-1} in Thailand.

Notably, yields and requirements for biofuel crops vary widely over different production systems and regions. But mere data about yields is of little use when considering biofuels, what we now need to know is the maximal yield per unit of GHG produced. A recent paper by Melillo et al (2009) indicates that nitrous oxide release from fertilizer use is the most serious problem of GHG balance. Data are lacking on rates of release, number of applications, formulation and other factors and hence experiments will need to be carried out to assess optimal applications. Moreover, Johnston et al (2009) questioned the data frequently presented in biofuels journals and decided to compare this data with their own calculations, based on the best available global agricultural census data. They found that biofuel yield data are often taken from a single location, sometimes a yield trial and are frequently overestimated by 100% or more. They conclude that "a more detailed, geographically-specific analysis of (actual and potential) yields is necessary."

The difficulties of accurately estimating yields are further exacerbated by the likely future changes due to climate change. In tropical regions especially, many crop yields are expected to decline due to increased temperature, increased pests and disease, more chaotic rainfall and even sea level rise (Contribution of Working Group II to the Fourth Assessment Report of the IPCC, 2007). Indeed, some evidence already exists that yields have been negatively affected by increased temperatures. Lobell and Field (2007) estimate that warming since 1981 has resulted in annual combined losses in wheat, maize and barley crops representing roughly 40 million tons (Mt) or $5 billion per year by 2002. A model developed by Schlenker and Roberts (2009) without ILUC effects suggests that area-weighted average yields of soy and maize will decrease by 30–46% before the end of the century under the slowest (B1) IPCC warming scenario and decrease by 63–82% under the most rapid warming scenario (A1FI, under the Hadley III model).

More generally, a recent report estimates that in developing countries, climate change will cause yield declines for the most important crops. South Asia will be particularly hard hit. Climate change will have varying effects on irrigated yields across regions, but irrigated yields for all crops in South Asia will experience large declines (Nelson 2009). Climate change will therefore cause its own ILUC and how this would relate to biofuel ILUC is difficult to imagine and is something that is, as far as we have been able to ascertain, unresearched.

Two very recent papers highlight the potential and the reality: on the one hand Burney et al (2010) estimate that each dollar invested in agricultural yields has resulted in 68 fewer kgC (249 kgCO2e) emissions relative to 1961 technology ($14.74/tC, or $4/tCO2e), avoiding 3.6 GtC (13.1 GtCO2e) per year. Their analysis indicates that investment in yield improvements compares favourably with other commonly proposed mitigation strategies and recommend that further yield improvements should be prominent among efforts to reduce future GHG emissions.

On the other hand Gibbs et al (2010) analyze FAO's pan-tropical Landsat database to examine pathways of agricultural expansion across the major tropical forest regions in the 1980s and 1990s. Over that period, across the tropics, they find that more than 55%of new agricultural land came at the expense of intact forests, and another 28% came from disturbed forests. It is therefore highly likely that considerable GHG savings could be made by judicious investment in research and implementation, but equally likely that this may not happen in many places.

Conclusion

There are multiple uncertainties with biofuel land use, both direct and indirect. There are major doubts about official estimates of available land, including those classed as unused, abandoned, degraded and marginal. Current estimates of the land that might be pressed into service in the next 40 years vary widely, by half an order of magnitude and more. Until these discrepancies are resolved, the various attempts to calculate and model what will happen as biofuel production expands should be regarded as extremely tentative, otherwise such estimates run the risk of becoming accepted as the truth by policy makers. In such a case as this, perhaps the lower range of estimates of available land should be adopted until more convincing data is available.

At the same time it seems possible that there would be substantial habitat destruction, especially tropical rainforest and savannah. Leading environmental scientists and international organizations such as UNEP all agree that further destruction of these systems is a major risk for climate change, biodiversity and ecosystem services. These issues will be covered further in Section 5. Substantial yield increase of existing agricultural lands is clearly desirable, but in many cases is by no means a foregone conclusion because of the various economic, cultural and infrastructure difficulties that lie in the way of scaling up such an outcome, especially with resource-poor farmers in developing countries. On top of this are the uncertainties of our future climate, where more extremes (high temperatures, droughts, floods) are predicted.

3. BIOFUELS FEEDSTOCK LCAS, ENERGY BALANCE AND CARBON FOOTPRINT: HOW IT RELATES TO ILUC

Biofuels LCAs

A recent review by van der Voet et al (2010) of no less than 67 biofuel LCAs found a range of problems. The studies do not adopt the same functional units; some express results in terms of amount of energy contained in the fuel, others the weight of the fuel or the yield per unit area (e.g. hectare) or even a composite measure. Such differences make comparison between studies difficult and lead to major differences in conclusions. Different allocation methods employed in the studies caused percentage GHG reductions compared to fossil fuels to vary from negative to above 100%.

The authors also found that the system boundaries vary between studies, reflecting their different purposes. Hence some are well-to-wheel, others are well-to-tank, cradle-to-gate (where 'gate' means the final product less costs of delivery to the tank) and even cradle-to-grave where the whole transport system is evaluated, including the car and the road. The latter is the most complete and indeed is surely needed if society is to evaluate the full costs of our current free-wheeling life styles. But by so doing, these most comprehensive studies tend to reduce the overall differences between fuel stocks, which is often the centre of interest.

At the heart of this is a fundamental problem: LCAs were never designed to cover wide-ranging questions of such global concern. LCAs are, by concept, a way of determining costs and impacts of a particular process – they are especially useful for firms looking to reduce costs of energy and materials for a particular supply chain, or of reducing environmental pollution; Coca-Cola and Mobil Oil were early adopters. It is easy for a company to use LCAs, because they can be reduced to a bottom line expressed in terms of money saved.

As Finnveden et al (2009) point out, not all types of impacts are equally well covered in a typical LCA. For example, the methods for the impact assessment of land use, including impacts on biodiversity, and resource aspects, including freshwater resources, are problematic and need to be improved. They also believe that there is a growing realization of the need to match the aims of the study, the questions being asked and the choices made. For example, if the aim of a study is to assess the consequences of a choice, the data used and the system boundaries chosen should reflect these consequences. The data and system boundaries used can then be discussed and assessed in relation to their appropriateness for this specific aim.

In the simplest analysis, biofuels are considered to be carbon neutral because CO_2 released during biofuel combustion is offset by carbon fixation during plant growth. However, GHGs can be produced during production and carbon balance can only be determined by a LCA (Koh and Ghazoul 2008). LCAs follow the impact of a product on the environment throughout its life span, through extraction of raw materials, conversion, manufacture, transport and use, to disposal of the product at the end of its useful life and management of the waste (Berg 1997). Using this approach, land, water, carbon footprints and energy balances can be calculated.

Another method to evaluate the effects of LUC (DLUC and ILUC) developed by García-Quijano et al (2007) uses 17 quantitative indicators to describe impacts on water, soil, vegetation cover and biodiversity. This method calculates impact of LUC and occupation relative to the potential natural vegetation of a certain location. Ecological impacts are evaluated specifically for soil, biomass, vegetation structure and water per functional unit. By expressing the impacts in a relative way (generally by percentage), the land use impacts become site-independent and globally applicable and comparable. The application of different versions of this methodology in different environments and on different production systems have proven to result in understandable and realistic outcomes.

Nevertheless, the LCA process is by no means straightforward. Gnansounou et al (2008) for example, found significant biases stemming from a range of factors. They found that the estimated GHG balance of wheat-based ethanol was highly sensitive to the method used to allocate impacts between co-products, type of reference system, type of land-use change, choice of functional unit and type of fuel blend. Depending on the methodological choices made, variation of life-cycle GHG emissions with respect to gasoline ranged from -107% to +120%. They conclude that several LCA studies are not transparent enough and methodological choices can easily turn a positive GHG balance into a negative one. It is therefore very important to establish agreed evaluation methods.

Cherubini (2010) has just reviewed a wide range of methodological concerns and identifies several areas that lead to diverging results. These include type of biomass source, conversion technologies, input data, end-use technologies, allocation method, system boundaries, reference energy system and other assumptions such as land-use change effects, soil N2O emissions, data quality and age. He lists 18 guidelines and recommendations which are too numerous to detail here, so we mention just one.

When agricultural residues are used as raw materials for energy generation (e.g. in the case of sugar cane), best management practices and above-ground residue harvest rates need to be established for minimum amount of crop residue that must be retained on the soil to maintain soil organic carbon, minimizing erosion and protecting soil quality and productivity. He suggests that this very complex issue (which is ignored in some studies) should be addressed regionally if not on a field or even subfield basis. Rotation, tillage and fertilization management, soil properties and climate will all play major roles in determining the amount of crop residue that can be removed in a sustainable system.

Energy Balance

A cardinal requirement of any energy generation business is that it should generate more energy than is consumed by the generation process. This balance is called the Energy Return On Investment (EROI) and has been the subject of much recent debate and confusion. With fossil fuels it was never an issue since, as Solomon (2010) points out, in the 1930s, the US production ratio was about 100:1. Latterly though the ratio has fallen to at best 20:1 Hall et al (2009); and the ratios calculated for biofuels are always lower than this.

A review of 10 papers on corn and cellulosic energetics by Hammerschlag (2006) concluded that for cellulosic ethanol EROI, three of four studies estimated the range as 4.4:1 to 6.6:1, whilst Farrell et al (2006) reported values as high as 11:1. For existing corn based ethanol operations on the other hand, EROI ranged from 1.3:1 to 1.65:1 in five of six studies, with Pimentel and Patzek's (2005) estimations being an exception, showing negative gain of 0.7:1. Pimentel and Patzek's estimates did not account for the use of co-products.

This highlights a significant issue raised in detail by Giampietro and Mayumi (2009): there is no standard way to calculate EROI. It depends on a range of indirect factors and hence has parallels to the ILUC problem. For instance, for a simple system such as a smallholder farmer growing a biofuel crop, what counts towards energy inputs? Is it just the farmer's direct energy inputs to produce the crop? Or does it include his/her family's energy costs, since the family is the overhead that ensures a sustainable farming future? And what about the sunken fossil fuel energy costs in the equipment he uses, and how much more energy expensive will they be in a future when they too have to be produced by burning biofuels? Hall et al (2009) state that since most biofuels have EROI's of less than 3:1 they must be subsidized by fossil fuels to be useful.

Additionally, Giampietro and Mayumi point out that the conventional analysis of EROI misses out the implications of the power level of the system. Differences in scale imply completely different sets of internal and external constraints. What is clear, is that with the very high historical gains of fossil fuel energy production, human society has never needed to seriously consider EROI; now however, with the much lower energy gains of biofuel systems, the way we evaluate a system's energy gain needs very careful consideration.

Carbon Footprint

There are significant differences between biofuel crops in their GHG balances. Figure 2 demonstrates the wide estimated ranges from the available data (Menichetti and Otto 2009). Palm oil is not included because its full range includes a value of -868% for GHG savings when grown on peat. Overall, sugar cane and sunflower display the most favourable balances, though all these must be regarded as tentative, given the almost universal tendency to over-estimate yields as mentioned above.

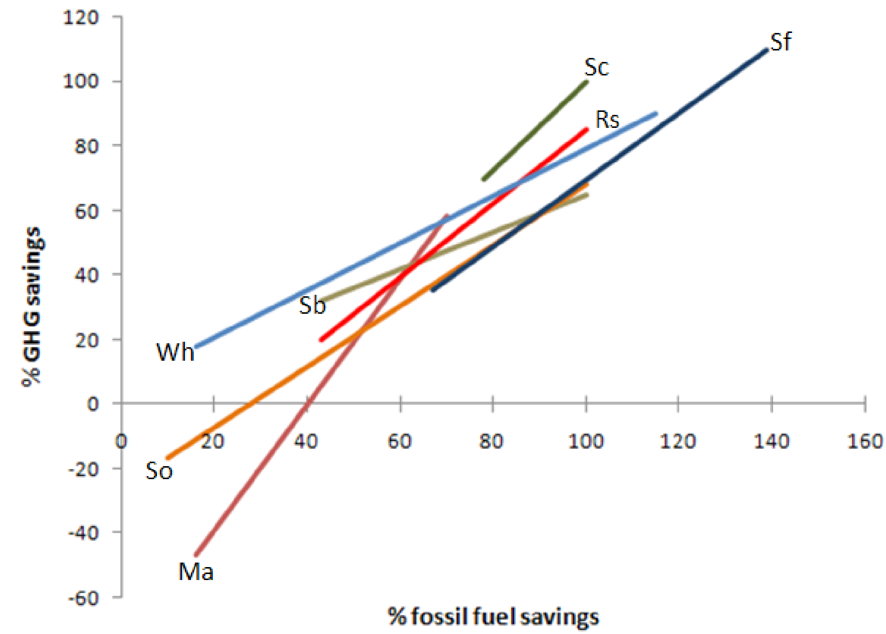

Figure 2: Ranges of estimated fossil fuel and GHG savings for maize (Ma), soybean (So), wheat (Wh), sugarbeet (Sb), sugar cane (Sc), rape seed (Rs) and sunflower (Sf). % fossil fuel savings refers to the reduction in fossil fuel use that would be achieved by adopting the biofuel in question. The ideal biofuel would be a short line located in the top right of the graph. Data from Menichetti and Otto (2009).

Globally, most of the discussion of biofuels LUC has focussed on impacts on carbon cycling or carbon footprint. Koh and Ghazoul (2008) analysed studies conducted during the last 15 years. They demonstrated that the replacement of petrol or diesel by biofuels can reduce GHG emissions by 31% for bioethanol, 54% for biodiesel, and 71% for cellulosic ethanol. Sugarcane bioethanol had the greatest GHG savings, and this has been reflected in analyses conducted in the U.S. for the federal Renewable Fuels Standard program (RFS2).

According to the Intergovernmental Panel on Climate Change (2000), LUC generally (primarily deforestation) was responsible for 20% of global CO_2 release from 1989 to 1998. If remaining forested lands are also converted to biofuels, carbon dioxide emissions will increase. Recently Gibbs et al (2010) provide new evidence that expansion of farming is a major cause of forest loss.

In many cases, conversion will result in significant above- and belowground carbon losses (Figure 3), creating carbon payback times of decades or even centuries (Fargione et al 2008). However, this is mainly dependent on the carbon stocks of the previous land use, plus the land management patterns post conversion, rather than the biofuel crop *per se*.

Yet, these analyses use general figures that need to be put into context. While it is relatively easy to estimate changes in above-ground carbon stock, as these are proportional to biomass, carbon changes in soils are more complex. The carbon balances of terrestrial ecosystems are uncertain and there are errors in measurements, but perhaps most importantly due to methodological problems resulting in incomplete accounting (Houghton 2003). There is a lack of data on carbon dynamics, particularly in tropical systems, from where the greater part of carbon emissions is expected.

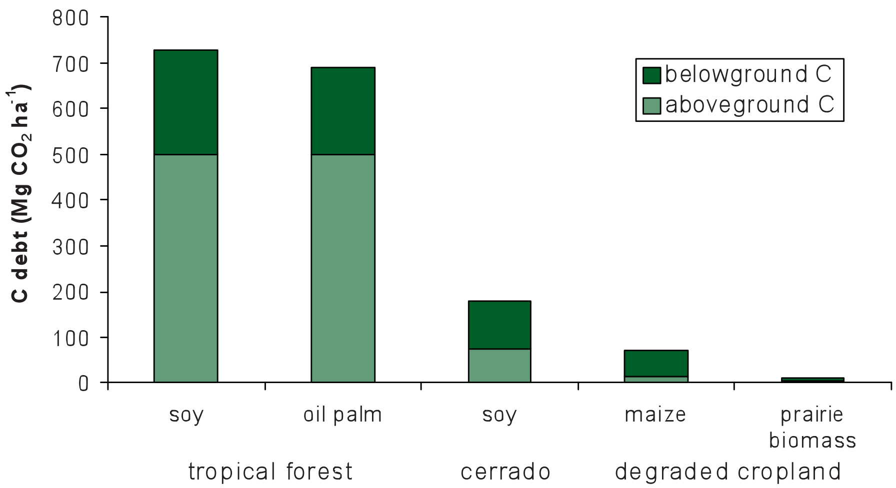

Figure 3: Above and below-ground carbon (C expressed in megagrams = tonnes) debts created in land use conversion to selected biofuel crops (Norgrove 2010, adapted after Fargione et al 2008).

There is also much uncertainty regarding the various sinks of CO_2 in natural ecosystems. Bondeau et al (2007) summarise ranges in estimated agriculture related carbon fluxes listed in recent papers. Estimates varied over an enormous range, from 0.6 to 3.0 megatonnes C yr-1, (Schimel et al 2001, House et al 2003). This huge uncertainty reflects large differences in estimates of deforestation rates and in the size of the terrestrial carbon sink.

Generally it is assumed that converting native systems to cultivation reduces soil carbon through increased soil respiration and loss of soil organic carbon (SOC). In North America, for example, there were large decreases in soil carbon when prairies were ploughed for the first time in the latter part of the 19th Century (Tiessen and Stewart 1983), estimated by Wilson (1978) to have been 3.7 Pg carbon p.a. between 1860 and 1890. Nevertheless there are many management factors affecting this dynamic. These include nitrogen status, tillage, and the crop selected.

For example, it is suggested that nitrogen fertilization can increase carbon mineralization of recalcitrant soil carbon pools (Dijkstra et al 2005) by inducing changes in the activity of ligninase enzymes (Zech et al 1994, Dijkstra et al 2004). In this case, carbon storage in soils would be greater in the long run under N-amended agricultural soils than under native vegetation. Yet, this hypothesis has been challenged by Cadisch and Giller (2001) who found evidence against a direct lignin pathway to soil organic matter (SOM) formation: a fertilization experiment they performed found that only the labile fractions of soil carbon increased rather than the recalcitrant fractions.

Additionally, Melillo et al (2009) using linked economic and terrestrial biogeochemistry models, predict that in a global cellulosic bioenergy program, ILUC will be responsible for substantially more carbon loss (up to twice as much) than direct land use; finding that through predicted increases in fertilizer use, nitrous oxide emissions will eventually be more important than carbon losses themselves in terms of warming potential. Their analysis, the most comprehensive to date, therefore shows that DLUC and ILUC associated with expanding global biofuels programs have the potential to release large quantities of GHGs into the atmosphere.

Melillo and his colleagues simulated two global land-use scenarios in their study. In Case 1, natural areas are converted to meet increased demand for biofuels production land. In Case 2, there is less willingness to convert land and existing managed land is used more intensely. The model predicts that, in both scenarios, land devoted to biofuels will become greater than the total area currently devoted to crops by the end of the 21st century. Case 1 will result in more carbon loss than Case 2, especially at mid-century. In addition, indirect land use will be responsible for substantially greater carbon losses (up to twice as much) than direct land use.

Balesdent et al (2000) compiled a review on the effects of tillage on soil carbon dynamics. They concluded that no general relationships could be discerned as tillage effects interact strongly with local climate, soil physical properties, and microbial populations. Tillage disrupts soil structure by breaking macroaggregates. Microaggregates are dispersed and this alters SOM decomposition but the extent of change depends on the previous land use and the time lag since conversion. To predict better the consequences of tillage on SOM turnover, more quantitative studies are needed.

Solomon et al (2002), working in the humid zone of Southeast Ethiopia reported that topsoil SOC reduced from 58-63 Mg ha^{-1} under humid forest to 34-40 Mg ha^{-1} in maize fields. Tchienkoua and Zech (2004) looked at SOC under intercropped food crop systems and compared this with areas that had been converted to *Eucalyptus* and tea plantations. Conversion led to significant increases in SOC (by a factor of approximately 2 for both trajectories). Tchienkoua and Zech (2004) stated that this was favoured by low temperature fluctuations and by allophone, a substance that reduces decomposition rate of polysaccharides and glucose. Other authors have found increases in SOC when rainforest is converted to improved pasture. For example, Boddey et al (2002) report that SOC under improved pasture of Brachiaria in South America increased compared with the previous rainforest. Such mechanisms involve the deposition of recalcitrant root residues high in lignin and tannin at deeper soil layers due to root turnover by deep rooting grasses.

There are many methodological problems associated with the measurement of soil carbon. For example, to obtain an accurate estimate of soil carbon in Mg ha^{-1}, it is necessary to simultaneously analyse soil carbon concentrations and soil bulk density to a depth where the total carbon contribution of that depth fraction to total soil is insignificant. Yet, often soil bulk density estimates are not done, they are inherently difficult to do on ploughed soil, and methods used vary (core method versus clod method). Below 20cm, bulk density measures are increasingly destructive. Many authors have only estimated soil bulk density in the topsoil although bulk density at deeper layers is difficult to predict from this parameter.

Second, different authors have used different extraction techniques for soil carbon. For example, the use of the Heanes (1984) method will give different results to the Walkley and Black method (Walkley and Black 1934). Furthermore, the temperature used in the Walkley and Black extraction affects the results with greater carbon extracted at higher temperatures. Method standardization is therefore essential. Regarding measurements of carbon fluxes, the least labour intensive and most capital intensive measurement of soil respiration is by using an infrared gas analyzer.

Nonetheless, this gives only a spot value and requires simultaneous measurement of soil temperature and water content. As respiration rate will vary greatly diurnally, repeated measures over a representative 24-hour period are required. Other methods include the use of soda lime, left in an enclosed container over a fixed area of soil for 24 hours and weighed before and after to determine carbon uptake. This gives an integral measure of soil respiration and making measurements at different times of year allows an estimation of yearly fluxes. This method requires numerous titrations or, if solid soda lime is used, precise weighing of the material before and after.

Conclusion

The uncertainties associated with ILUC are compounded by methodological problems with the LCA process itself. The issues are multiple and complex and would require a separate study to cover adequately. As things stand, it would seem that little confidence can be placed in any one LCA study unless every assumption is transparently listed and sufficient emphasis is placed on any remaining uncertainties. At the root of this problem is that current commercial biofuels have much lower EROI ratios than fossil fuels, so that there is little or no safety factor to allow for, say, local differences in yields or energy costs of irrigation for example. Much clearer guidelines are needed for field operators and the implications for standard-setting are possibly very onerous. Furthermore, it would seem that the energy expended in ILUC activities are currently not factored into EROI calculations, which could further add to the doubts surrounding the true sustainable energy gains accrued through biofuels to society.

4. ADDITIONAL ENVIRONMENTAL IMPACTS LINKED TO ILUC

Additional environmental impacts that have been linked to ILUC include biodiversity and water footprint. This section briefly details these concerns and their link to biofuels ILUC.

Biodiversity Concerns

Attempts to halt biodiversity decline by 2010 as stated in the Convention on Biodiversity are now widely agreed to have failed. It is also generally acknowledged that further losses of natural habitats is extremely ill-advised, because of risk of extinction and the loss of ecosystem services that this will entail. Forest losses in Southeast Asia for example have accelerated in recent years. Koh (2007) points out that the rate of loss of old growth forests in Indonesia has increased from 2.3% per year in the period 1990–2000 to 2.7% per year in 2000–2005. Old growth forests are also being lost at increasing rates in Cambodia (1.0 to 6.7%) and Vietnam (6.9 to14.6%) between the two time periods. Much of the forest loss is due to expansion of agricultural land (Gibbs et al 2010), for commodity crops including biofuels feedstocks. This will either directly or indirectly only tend to further increase natural habitat loss.

A study on biodiversity in oil palm plantations (Fitzherbert et al 2008) concludes that they are a poor substitute for native tropical forests and support few species of conservation importance, and affect biodiversity in adjacent habitats through fragmentation, edge effects and pollution. The authors suggest that there is enough non-forested land suitable for plantation development to allow large increases in production without further deforestation, but political inertia, competing priorities and lack of capacity and understanding, not to mention high levels of demand for timber and palm oil, often make it attractive to clear forests.

Moreover, some biofuel plant species may become invasive in non-native ecosystems and hence, affect biodiversity and ecosystem services. For example, jatropha is considered as an invasive weed in South Africa and Australia although studies on its actual or potential ecological impact are as yet unavailable. A further and serious problem with greatly expanding biofuel production is that optimal yields and efficiencies are gained with large monocropped systems. As with all monocultures, such large expanses are inherently susceptible to attack by pests. History is full of grandiose schemes for major production schemes that have faltered or been serious curbed by these factors (e.g. Grandin 2009).

Pests frequently account for 40+% crop losses (Oerke and Dehne 1997) and biofuel crops are no different but so far little studied. We know though that pests can cause major losses to crops that can be used as biofuels. For example, basal stem rot (BSR) is the most serious constraint of oil palm in South East Asia. After 10 or more years, yields may be reduced by 25% or more (Ariffin et al 2000) but importantly, the disease appears earlier in replanted areas. Therefore successful management of BSR is essential to allow replanting on currently cultivated land and to reduce further deforestation.

Theoretically at least, cellulosic biofuels based on a mix of grass species might experience fewer pest and disease losses since this could provide a stable combination of species likely to possess a relatively high level of overall genetic resistance with, if managed effectively, a reasonable balance of pests and natural enemies. Currently though, this subject seems to be completely unstudied. Theoretically too, biofuel plants introduced to non-indigenous areas may be preferred because they would be considered likely to be attacked by a smaller guild of pests and diseases but there is always a risk of pests and diseases from closely related crops spreading to the introduced crop. Also there are potential problems with invasiveness – the ideal biofuel plant would be one that grows vigorously in marginal conditions and this is precisely the characteristic of many invasive plant species. Invasives have the potential to cause significant economic loss: In the US alone, annual losses of over $120 billion have been documented from the effects and control of introductions of invasive species.

Potential Impacts on Water Resources

Currently food and fibre production systems use 86% of worldwide freshwater (Hoekstra and Chapagain 2007). Table 2 details water footprints for some common biofuels. Sugarbeet, maize, sugar cane and potato bioethanol have low water footprints. The biodiesel crops, soy and rape have very high water footprints. Some of these values (for example, for jatropha) have been disputed by others however (Pfister and Hellweg 2009).

Crop	Total water footprint (m^3 per GJ electricity)
Sugar beet	46
Maize	50
Sugar cane	50
Barley	70
Rye	77
Paddy rice	85
Wheat	93
Potato	105
Cassava	148
Soybean	173
Sorghum	180
Rapeseed	383
Jatropha	396

Table 2: Total weighted global average water footprint for 13 crops (from Gerbens-Leenes et al 2009).

The International Water Management Institute (IWMI 2008) suggests that globally, there is enough water to produce both food and biofuel. But, in countries where water is already scarce, such as India, growing biofuel crops will aggravate existing problems. Difference in requirements are highly site-specific, for example producing one litre of ethanol from sugarcane takes nearly 3,500 litres of irrigation water in India, but just 90 litres of irrigation water in Brazil.

The Committee on Water Implications of Biofuels Production in the United States (National Research Council, 2007) also concluded that there are many uncertainties in estimating consumptive water use of the biofuel feedstocks of the future. Water data are less available for some of the proposed cellulosic feedstocks, for example, native grasses on marginal lands, than for widespread and common crops such as corn, soybeans, sorghum, and others. Neither the current consumptive water use of the marginal lands nor the potential water demand of the native grasses is well known. Further, while irrigation of native grass today would be unusual, this could easily change as production of cellulosic ethanol gets underway. In the next 5 to 10 years, increased agricultural production for biofuels will probably not alter the US national-aggregate view of water use. However, there are likely to be significant regional and local impacts where water resources are already stressed.

Conclusion

Compounding the uncertainties revealed in previous sections, we see that a broad range of other environmental effects add further difficulties in accurately predicting the effects of biofuel production in a given location at some point in the future. The main problem resides in the magnitude of localized effects, including climatic variables, availability and therefore cost of water as well as the various pests and diseases present. This strongly suggests therefore that extensive pre-testing at the pilot stage is required for all prospective biofuel projects in every new setting. The problem is that ILUC effects will only truly be understood in retrospect after major programs are carried through. For this reason, ILUC modelling becomes the only way to judge the possible impacts and this is covered in the following section.

5. EXAMPLES OF SELECT BIOFUELS ILUC STUDIES

In this section, we will discuss examples of different models used to quantify ILUC as well as their shortcomings, followed by some examples of biofuels ILUC findings in recent studies. Most authors expect that an increase in biofuel production will lead to LUC, either directly or indirectly (for example, see Righelato and Spracklen 2007). Permutations and combinations of LUC are endless. For example, for a land use trajectory where the initial land use system is tropical forest, three classes of conversion were distinguished by Coulter (1992):

- High input-high output systems (tree crops such as rubber, oil palm). This is common in South East Asia, where farmers clear land that has been logged (Moad and Whitmore 1994);
- Pasture production for cattle farming usually after one upland rice cycle. This is the major type land conversion in Honduras (Sunderlin and Rodriguez 1996), Puerto Rico (Aide et al 1996), and Latin America (FAO 1997) and is the dominant option for smallholders;
- Low input-low output slash and burn agriculture. This is the most common cause of deforestation in Africa (FAO 1997) and is frequent in Asia.

The Many Approaches to Modelling ILUC

Attempts to quantify LUC rely on models, and there are many approaches, which we present but in brief here. Pontius and Neeti (2010) identified the following categories:

- Models containing calibration algorithms;
- Statistical models creating a probability function as an output that require calibration using historic data, such as CLUE (http://www.cluemodel.nl/), used together with scenario modelling (Verburg et al 2002);
- Agent-based models simulate decision-making by human actors who influence land change, and tend to have many input parameters (Manson and Evans 2007).

Other models combine the above techniques (Pontius et al 2007). All models have parameters where values need to be assigned to run the model. For example, the Forest Land Orientated Resources Envisioning System (FLORES) has been used and adapted to understand LUC at the humid forest margins of South East Asia and Central Africa (Robiglio et al 2003, Vanclay 2003). The assumptions of FLORES include that land-use decisions are complex and that actors consider all of their options within the constraints of the financial, labour and technical resources available as well as within their knowledge and perception limitations (Vanclay 2003).

Bondeau et al (2007) described the Lund–Potsdam–Jena model of managed Land (LPJmL) developed by Sitch et al (2003). This model looks at the changing area of croplands. According to their assumptions, total cropland area increased rapidly until the 1950s. It then slowed and reached an equilibrium position in the 1980s when tropical deforestation rate was balanced by temperate afforestation (Ramankutty and Foley 1999) data set. Results therefore disagree with those of Houghton (2003) from 1970 onwards.

As another example, regulators in the U.S. have used a combination of modelling tools to analyse lifecycle GHG emissions and biofuel ILUC impacts. They are not limited to but include:

- The Forestry and Agricultural Sector Optimization Model (FASOM): A partial equilibrium economic model of the U.S. forest and agricultural sectors that tracks over 2,000 production inputs for field crops, livestock and biofuels and accounts for GHG emissions changes from most agricultural activities. Regulators selected the FASOM model because comprehensive forestry and agricultural sector model that tracks over 2,000 production possibilities for field crops, livestock, and biofuels for private lands in the contiguous U.S.
- Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET): A spreadsheet analysis tool developed by Argonne National Laboratories: GREET includes the GHG emissions associated with the production and combustion of fossil fuels. GREET also estimates the GHG emissions associated with electricity production required for agriculture and biofuel production.
- Integrated Food and Agricultural Policy and Research-Center for Agricultural and Rural Development (FAPRI-CARD) at Iowa State University: These models capture the biological, technical, and economic relationships among key variables within a particular commodity and across commodities.
- The Global Trade Analysis Project (GTAP) This model was developed to estimate global flows in agricultural commodities in response to prices and policy changes.

Sources of uncertainty and error in the outcome of model runs may derive from:

- The input data, digital maps and remote sensing interpretation;
- How well algorithms included in the model express important processes and simulate dominant LUCs;
- Uncertainty in predicting future LUC processes. Decision making involves human free will, which is difficult to model and maybe illogical (Pontius and Neeti 2010).

Some examples of errors in LUC assessments and models are below. They include:

- Misinterpretation of the extent of the original vegetation;
- Difficulty in distinguishing between certain land uses;
- Treating LUC as linear and ignoring cyclical processes such as shifting cultivation (Mertens and Lambin 2000).

Deforestation in West Africa is given as an example to illustrate these error types. According to estimated deforestation rates in West Africa, 90% of the 'original' moist forest has been lost (Bryant et al 1997). Slash and burn agriculture is cited as the major cause of forest loss (FAO 1997). However, the extent of the so-called original forest is unclear. Researchers and early explorers during the colonial era who observed forest patches with tall trees in the savannah or in bush land assumed that these indicated the past presence of a more extensive closed canopy forest of which they were mere relicts (Chevalier 1909; Aubréville1938, 1949) and thus the entire area of the surrounding savannah was assumed to be previously forest.

This conclusion has been challenged by researchers in fields as disparate as anthropology (Fairhead and Leach 1994, 1996; Bassett and Koli Bi 2000, Ickowitz 2006), botany (Goetze et al 2006, Hennenberg et al 2005) and palynology (Maley and Brenac 1998, Vincens et al 2000). Fairhead and Leach (1994, 1996), have analysed reports in West Africa and concluded that forest cover has increased in the last century. Tree cover has been enhanced by cultivation along the forest savannah boundaries by promoting forest succession after removal of grasses through hoeing. Other evidence has attributed major changes in vegetation cover to climate changes (Maley and Brenac 1998).

Remote sensing interpretations of land use cover are prone to error, if not backed up with extensive ground truthing, due to the difficulty of distinguishing certain land use types. For example, Thenkabail (1999), analysed HRV SPOT data of central Cameroon from March 1995. He concluded that *Imperata cylindrica* (spear grass), an aggressive weed that spreads after cultivation and can cause farmers to abandon land, occupied more than 10% of the land area. This area was subsequently classified by the Global Alternatives to Slash and Burn Programme (Kotto Same et al 2000) as having a high human population density, high intensity and consequently "only 4% of land remains covered by primary forest' and 'the stock of forest resources has been seriously degraded".

Yet, more recent work revealed that *Imperata cylindrica* coverage is low. According to the reports of villagers, most of this land has not been cultivated recently (Gockowski personal communication, Norgrove 2006). This misinterpretation of remote sensing data is understandable; Mertens and Lambin (2000) working near Bertoua in East Cameroon looked at land cover trajectories from 1973 to 1991 and found that nearly 10% of land was classified as stable savannah or permanent agriculture, and these two land use types were indistinguishable. Doumenge et al (2001), also working in Cameroon, stated that it was not possible to distinguish natural forest-savannah mosaics from cultivated areas.

Grieg-Gran (2006) reported that deforestation in the Congo Basin is driven by smallholder shifting cultivation. Certainly, smallholders clear land for agriculture, however, net clearance requires subtracting the amount of land that is returning to forest fallow and this is often overlooked. Robiglio and Sinclair (2007) compared the aerial photos from the 1950s, and satellite imageries of 1980s and 2001 and demonstrated that in some parts of southern Cameroon the area of land previously in agriculture but currently in fallow was greater than the area of land previously in forest and currently under agriculture, in both the 1980s and 2001.

The Searchinger Analysis of Biofuels ILUC

Recent studies on biofuels and ILUC have been greatly influenced by the paper of Searchinger et al (2008) that discusses the hypothetical ILUC impacts of increased biofuel production. Their paper looked at what impact increasing maize bioethanol production in the U.S. by 75%, an additional 56 billion litres, by 2016 would have on land use. These figures were input to the FAPRI-CARD model. This would mean that 12.8 million ha of existing cropland in the U.S. would be diverted to maize production, achieved by changing the land use of areas currently under soy and wheat and U.S. exports of wheat and soy would decrease (wheat by 31%).

The model predicted that price increases would be 40%, 17% and 20% for maize, wheat and soy, respectively. They hypothesised that this would lead to more than 10 million hectares being brought into production elsewhere in the world, particularly Brazil for soy and China for wheat and maize and particularly from forest clearance. This would result in the release of 3.8 billion mega-tons of CO_2-equivalent GHGs – a carbon debt that would take more than 150 years to repay (Searchinger et al 2008). While the Searchinger paper has been widely quoted, there have been many papers criticizing the assumptions made, its conclusions and their general application.

According to Mathews and Tan (2009), the Searchinger paper has the following flaws. First, the expected ethanol consumption of 56 billion litres by 2016 is a weak assumption as is the concept that this would be obtained exclusively from maize grown in the U.S. It has been shown in the current paper that bioethanol production is more efficiently produced from other crops, even within the U.S. It would therefore be more realistic to look at other domestic sources of bioethanol or to suggest that bioethanol from sugar cane is imported from Brazil, but this idea is not explored. So it is assumed that needs are met entirely within the U.S. Furthermore, the supply and demand elasticities used are based on historical figures.

The calculations of the extra hectarage needed in other countries to make up for diversion of maize to ethanol specify locations (Brazil, India, China) and assume that this production will come from land conversion from forest. Figures are based on observations from the 1990s in countries such as China and India (Houghton 2003). They do not consider intensification, yield increases, crop switching or use of degraded land as options. They do not consider the complexity of factors and drivers in LUC and uncertainty in the models and there is much literature showing that LUC is not driven only by agricultural expansion but that timber extraction and road building are major interacting factors.

Also, as discussed earlier, carbon emission figures presented by Houghton (2003) are larger than those from other authors (Bondeau et al 2007 and others) who highlight the uncertainty in global carbon dynamics. The figures presented on carbon losses also do not take into account cropping management (Kim et al 2009) although the importance of considering tillage regimes and nitrogen usage is highlighted earlier in this paper. Instead there is an arbitrary assumption that when land is cultivated there is a 25% loss in SOC, although in the previous section of this paper it is demonstrated that SOC can increase in certain contexts. Other problems are that there are no margins of error quoted in the paper and no discussion of the assumptions used.

Searchinger (2008) rebutted these technical objections and recent work by Yan et al (2010) has provided further support for his position on ILUC. They conclude, from both U.S. and Chinese data, that soybean, rapeseed and jatropha biodiesel all appear at first sight to have favourably low GHG emissions in relation to diesel, but that their "well to wheel" GHG releases are increased significantly when land-use change is taken into account. Hence biodiesel from soybean, rapeseed or jatropha could cut emissions but by very little if carbon-storing forests and grasslands are cleared to grow these crops. Only cellulosic biomass has significant potential for cutting transport emissions, because it has minimal land-use impacts. They warn that converting grasslands in the U.S. to maize fields for bioethanol production could cause a huge carbon debt through direct land-use change. Diverting U.S. maize exports to bioethanol production could potentially cause an even greater carbon debt through ILUC.

Finally, and most recently, further support for Searchinger comes from Lapola et al (2010) who looked at potential land-use changes from biofuel expansion in Brazil which almost certainly will continue to be a major source of global biofuels. "*To fill the biofuel production targets for 2020, sugarcane would require an additional 57,200 sq km and soybean an additional 108,100 sq km of land. Roughly 88% of this expansion (145,700 sq km) would take place in areas previously used as rangeland*," say the authors. Their simulations suggest that direct deforestation would mean destruction of a fairly modest 1,800 sq km of forest and 2,000 sq km of woody savannah in the case of soybean. However, their models also suggest that large areas of rainforest and cerrado (savannah) would be indirectly impacted as displaced cattle ranchers find such new lands to exploit.

When it came to carbon payback times, the authors found that four years would be needed to compensate for direct emissions from conversion for cane relative to emissions from fossil fuels and 35 years for soy biodiesel. But factoring in ILUC – in this case cattle ranching displaced to forest lands by cropland expansion – dramatically extends the amount of time needed for emissions savings from biofuel production to compensate for emissions from deforestation: by 40 years for sugarcane ethanol and 211 years for soy biodiesel. *"Indirect land-use change could considerably compromise the GHG savings from growing biofuels, mainly by pushing rangeland frontier into the Amazon forest and Brazilian Cerrado savanna,"* Lapola and colleagues write. The authors suggest that planting oil palm instead of sugarcane or soy on pasture lands would result in some direct deforestation (300 sq km) but significantly reduce emissions from ILUC due to the crop's substantially higher oil yield.

Conclusion

To estimate the effects of ILUC into the future, modelling is required, but there is no standard and agreed method to do it, and no sign that a consensus is near. Indeed the current debate about ILUC between scientists is intense, as may be expected from a field of study that only opened up two years ago. Whatever the objections to the assumptions and methods employed by Searchinger et al (2008) it is surely undeniable that if the biofuel industry expands to the point where it is making a global impact on GHG emissions, then indirect effects will exist and become more important and possibly self-defeating.

As in previous sections, uncertainties abound, with doubts about fundamental measurements such as the availability of unassigned land, the extent to which marginal land can be utilized and the yields that can be expected in a future where availability of sufficient water is increasingly uncertain. All these factors and others lead to the inevitable conclusion that the outputs of models must be treated with considerable caution and, because of the global gravity of land use issues in a crowded world, that ILUC effects must be considered plausible and substantial until strong evidence to the contrary is provided.

In the concluding section we will elaborate on the multiple categories of uncertainty that need very careful definition and delimitation as first steps towards clarification of these complex issues. The situation is seemingly much more difficult than with climate change modelling, which at least can rely on one hundred years of accurate weather recordings, so that models can be back-casted. Hence the accuracy with which climate models reproduce past climate variations gives considerable confidence that modellers are on the right track. No such possibility exists for ILUC and associated biofuels issues.

6. REGULATORY AND LEGISLATIVE ACTIONS UNDERTAKEN TO CONTROL ILUC FROM BIOFUELS

Several regions or individual countries have incorporated ILUC estimations into LCAs of GHG emissions resulting from the production of renewable biofuels. Estimation of such unintended consequences of carbon emissions from LUC is an evolving scientific process with substantial data gaps and uncertainties. Nonetheless, legislative and regulatory action to address carbon emissions broadly, and the contribution of ILUC induced by mandated biofuels use specifically, is proceeding in parallel to the advancing science. Currently, there is no internationally agreed policy or methodology for addressing ILUC impacts for biofuels production and use. This section briefly describes the major regulatory and legislative actions taken to require ILUC considerations in the development of biofuels programs.

European Union: Renewable Energy Directive

On 17 December 2008, the European Parliament approved the Renewable Energy Sources Directive (COM/2008/19) (RED) and amendments to the existing Fuel Quality Directive (Directive 2009/30/EC) (FQD), which include sustainability criteria for the production and use of biofuels and requires ILUC to be considered in the development of these criteria. The Renewable Energy Directive (Directive 2009/28/EC) set the EU target of 10% for biofuel use in transportation fuels, whereas the Fuel Quality Directive established a Low Carbon Fuel Standard (LCFS) to achieve a 6% reduction in GHG emissions of transport fuels by 2020.

As part of the implementation of the increased biofuels production and use, the EU directed that calculation of GHG emissions include all main contributions, including the indirect effects. The directive did not specify the approach (methods for determining ILUC) or the defined limits for such determination, instead it directed the European Commission to develop the factors for ILUC impacts on GHG emissions based on the best available science, and to make proposals on how to address the issue of ILUC. Under the mandate, the Commission is to deliver its report on methodology and limits by 31 December 2010.

Directive 2009/28/EC *on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC*, also known as the Renewable Energy Directive or RED, presents several clauses on the need to carefully establish the sustainability criteria to monitor and reduce GHG emissions from transport fuels and biofuels. The directive text clearly indicates that emissions from domestic and international LUCs resulting from biofuels need to be incorporated into the calculations; however, it recognizes that the science needs to continue to develop to do so. The RED further recognizes that:

- Biofuel production should be sustainable and national programmes fulfil sustainability criteria;
- Biofuels and bioliquids should avoid destruction of biodiverse lands;
- GHG emissions should attempt to use actual values for carbon stocks associated with land use and conversions;
- Concrete methodology should be developed to minimize GHG emissions caused by ILUC and the best available scientific information should be analyzed.

As a legislative action by the EU, the RED has spelled out the requirements for implementing sustainability criteria that incorporate consideration of ILUC. Annex V of the RED provides for the rules for calculating the GHG impacts of biofuels, bioliquids and their fossil fuel comparators. The Annex V includes the following rules:

- Typical and default values for biofuels if produced with no net carbon emissions from land-use change;
- Estimated typical and default values for future biofuels that were not on the market or were on the market only in negligible quantities in January 2008, if produced with no net carbon emissions from land-use change;
- Specific methodology for calculation of GHG emissions from the production and use of transport fuels, biofuels and bioliquids; and
- Disaggregate default values for biofuels and bioliquids, and for processing, transport and distribution of fuels.

The EU recognized that increased demand for biofuels would result in increased agricultural land use and potentially this could include conversion of carbon-rich land areas into agricultural land that could cause adverse carbon emissions impacts. The RED includes provisions to prevent the risks of emissions from direct LUCs in the production of biofuels by defining lands that are not eligible to be used for producing feedstocks for biofuels under the Directive. Included in this restriction are high carbon stock lands such as wetlands and forested areas having canopy cover of 30% or more. Forested areas with a canopy cover between 10% and 30% must be included in the restriction unless it can be demonstrated that their carbon stock is low enough to justify conversion to biomass-feedstock within the rules set by the Directive. The European Commission has conducted a consultation to establish the definition for "highly diverse grasslands" to establish the criteria and geographic ranges that should be covered within the RED. The final conclusions from this consultation on grasslands definition are pending.

In March 2010, the European Commission released a large number of documents relating to its work on ILUC under the Directive 2009/28/EC, including available results from the Partial Equilibrium Modelling. These results indicate that a 1.25% increase in EU biofuel consumption would require around 5 million additional hectares of land globally. Results of a General Equilibrium Model were also released that analyzed different scenarios for biofuel use varying from 5.6% to 8.6% of road transport fuels. These results also showed that ILUC effects off-set part of the emissions benefits from the use of biofuels above 5.6% level. Furthermore, above this threshold, ILUC emissions increase at greater rate that can erode the environmental sustainability of biofuels.

The RED identified ILUC as an issue that needed further investigation and study. In response to this directive and timeline, the Commission published Terms of Reference for the Indirect LUC Impact of Biofuels. This reference builds on earlier work that examined overall economic and environmental impacts of the EU biofuels policy and specific trade issues associated with the policy. The subsequent reference establishes three modelling exercises on ILUC:

- Using a general equilibrium model;
- Using a partial equilibrium model;
- Comparing other global modelling approaches.

The purposes of this second phase of biofuels and ILUC study are to address questions raised in the earlier effort and to produce a more detailed and reliable estimate of ILUC impacts from improvements in databases and modelling. The outcome of this study is a report that analyses the global agricultural production, trade and environmental impact of the EU biofuels policy within the RED. Focus is on the ILUC effects of the main feedstocks used for biofuels production. The objective is to contribute to the impact assessment and report on ILUC and possible Commission proposals on how to best deal with ILUC under the RED.

To support this additional work and the possible proposals for dealing with ILUC, the Commission carried out a consultation (governmental and private inputs) on a defined range of options for addressing ILUC. Responses to the consultation were received from 17 countries and 59 organizations. Even though the deadline for the report on ILUC impacts on GHG emissions from the biofuels policy is not due until December 2010, the Commission is using the results of this consultation to help prepare a report (March 2010) for use by Member States in preparing their national Renewable Energy Action Plans, which must be submitted by the end of June 2010. The consultation demonstrated that:

- Member states are widely divided on the issue of ILUC, and no single policy option is favoured;
- No agreement exists either on the issue of ILUC outside the EU;
- Many commenters indicated that issues on ILUC are not well enough defined to determine the best policy options;
- Further scientific analysis and discussions are needed before ILUC policy can be established.

A more recent issue being discussed within the RED implementation is waste oils/residues, tallow, black liquor and tall oil traditionally used for feedstock to make soaps, detergents and other related chemicals, and now being more often used as substitutes for food-based (grains) feedstocks for biofuels production. The consequence of this substitution would be soaps/detergents/chemicals producers seeking out other economic feedstocks, such as palm oil that could result in ILUC impacts. Feedstocks that would go into production of next-generation renewable fuels will need to consider ILUC effects.

United Kingdom: Renewable Transport Fuel Obligation

The UK Renewable Transport Fuel Obligation (RTFO) program requires transport fuel suppliers provide 5% of their fuels from renewable sources by 2010. The requirement was authorized by the Energy Act of 2004, which came into effect in April 2008, and is intended to help the UK achieve the EU biofuels directive targets. Although not mandated by the legislation, the Renewable Fuels Agency (RFA) was asked to conduct a review of the impacts from this requirement and increased biofuels production, including consideration of ILUC and changes in food and other commodity supplies and pricing.

The RFA study, referred to as the Gallagher Review, was published in July 2008 and concluded that risks exist from increasing biofuels production and demand, and that although uncertainties exist in the estimations, feedstock production should avoid lands otherwise used for food crops.

The review also concluded that "quantification of GHG emissions from indirect land-use change requires subjective assumptions and contains considerable uncertainty." Because of this, the report recommended further investigation and study to better understand the impacts of indirect effects, including ILUC and other factors. The UK regulators are working closely with the EU officials on development of appropriate methodologies to take ILUC into account for GHG emissions from biofuels production and use.

United States: Renewable Fuels Standard Program

On 3 February 2010, the U.S. Environmental Protection Agency (EPA) issued the final regulations for the federal Renewable Fuels Standard Program (RFS2). This regulation makes changes to the program as required by the *Energy Independence and Security Act of 2007* (EISA; P.L. 110-140). The statute requires increased annual use of renewable fuels in transportation fuel, modifies definitions and criteria for feedstocks and renewable fuels made from them, and establishes GHG emissions reductions thresholds as determined by LCAs for these fuels. The LCAs must take into account the direct and indirect emissions impacts of the production and use of the renewable fuels.

The final regulations issued by EPA for the RFS2 program does not *directly* include provisions on ILUC or specific requirements for conducting LCA on biofuels. The EPA used the LCA (with incorporated ILUC impacts) process to help identify the renewable fuel pathways that meet the statutory GHG reduction thresholds, and thereby qualify for compliance under the RFS2 program. The final regulations include provisions for biofuel producers to petition the EPA for evaluation of new renewable fuel pathways. The RFS2 regulations require that biofuels producers conduct a certified engineering assessment and attest engagement for production processes and feedstock(s) used. The biofuels producer (either domestic or foreign) must also register into the program and maintain documentation and recordkeeping to ensure that the renewable fuel meets the requirements to qualify for use under the RFS2 program. This documentation must also indicate the renewable fuel feedstock source thereby allowing EPA to monitor land use.

Obligated parties for the RFS2 regulations include domestic and foreign producers and importers of transportation fuels used in the U.S. This regulation also establishes the 2010 RFS volume standard for each obligated party within the four categories of renewable fuels set in the EISA: conventional renewable fuel; advanced biofuel; biomass-based diesel fuel and cellulosic-based biofuel. This final regulation is effective on July 1, 2010, and the percentage standards apply to all gasoline and diesel fuel produced or imported in 2010. It must be emphasized that ILUC are incorporated into the LCA for biofuels to determine whether or not they qualify for the GHG emissions reductions required by the four biofuel categories under EISA – there are no specific standards on ILUC in the RFS2 regulation.

The EISA legislation established the general requirements for considering the lifecycle GHG emissions of renewable fuels and incorporation of direct and significant indirect emissions. The legislation also provides for definitions for renewable fuel and advanced biofuel as those produced from renewable biomass (also defined) that is used to replace or reduce fossil fuel. The provisions further provide definitions for each of the categories of qualified biofuels under the program, namely, renewable fuel (including conventional biofuel), advanced biofuel, cellulosic biofuel and biomass-based diesel.

It also established the meaning for baseline lifecycle GHG emissions. One of the most significant provisions in the statute is the setting of GHG emissions reductions thresholds for the renewable fuels to quality for compliance purposes under the RFS2 program. EPA was required to conduct a LCA of each biofuel type to determine whether or not it can meet the thresholds. The statute allows for EPA to consider flexibility for these reduction thresholds; however, in the final regulation the agency retained those specified by the law. EPA followed the mandate of the statute in considering the full lifecycle GHG emissions impacts of fuel production from both direct and indirect emissions, including significant emissions from LUCs. The EPA analyses attempted to incorporate the "most up-to-date" science and methodologies during the rulemaking effort. The agency recognized that LCA is an evolving discipline and plans to re-evaluate their analyses as new information becomes available. The EPA also intends to ask the National Academy of Sciences for assistance and input to the process.

Throughout the regulatory process for the RFS2, EPA solicited expert input to evaluate key components of EPA's methodology on LCA and LUC:

- Land use modelling, specifically the use of satellite data and land conversion GHG emission factors;
- Methods to account for the variable timing of GHG emissions associated with land use;
- GHG emissions from foreign crop production (both the modelling and data used); and
- How the models are used together to provide overall lifecycle estimates.

Based on public comments and scientific peer review, EPA agreed that it was important to take into account indirect emissions when conducting lifecycle emissions from biofuels. It was also clear that there were significant uncertainties associated with these analyses, particularly with regard to ILUC and the use of economic models to project future commodity market interactions that involve biofuels, feedstocks and agricultural products. Working closely with experts, other government agencies and industry, EPA quantified, to the extent possible, the uncertainty associated with indirect LUC emissions, including international changes, associated with increased biofuel production.

To manage the uncertainty around those international and indirect LUCs, EPA focused on three approaches:

- Getting the best information possible and updating analyses to narrow the uncertainty;
- Performing sensitivity analyses around key factors to test the impact on the results; and
- Establishing reasonable ranges of uncertainty and using probability distributions within these ranges in threshold assessment.

From its assessments, EPA concludes that the modelled indirect emissions from LUC, including international changes, were "significant" in terms of their relationship to total GHG emissions for given fuel pathways, as consistent with the mandate under EISA. The findings in these analyses were incorporated into the LCA for biofuels to determine whether or not they qualify for the GHG emissions reductions required by the four biofuel categories under EISA

California: Low-Carbon Fuels Standard

On 1 January 2010, the California Low Carbon Fuels Standard (LCFS) regulation became effective. The regulation is designed to reduce the state's GHG emissions from fuels used in the state by reducing the carbon intensity of the fuel supplied to the marketplace. This reduction in carbon intensity (CI) is being phased-in beginning in 2011 and will achieve a 10% reduction by 2020. In determining carbon intensity of fuels, the California Air Resources Board (CARB) conducted fuel LCAs that incorporated both direct and indirect impacts, including LUCs. The regulations were adopted on 23 April 2009, and final administrative approval issued on 12 January 2010. In developing the LCFS, the CARB established a process to evaluate the LCA, including direct and indirect effects, of GHG emissions of various fuel pathways. CARB modified available models to incorporate land use impacts for production of feedstocks used to make biofuels for the LCFS.

CARB calculates fuel CIs under the LCFS on a full lifecycle basis. This means that the CI value assigned to each fuel reflects the GHG emissions associated with that fuel's production, transport, storage, and use. Based on its work with university LUC researchers, CARB staff has concluded that the land use impacts of crop-based biofuels are significant, and must be included in LCFS fuel CIs. CARB believes that to exclude them would allow fuels with CIs that are similar to gasoline and diesel fuel to function as low-carbon fuels under the LCFS. CARB further believes this would delay the development of truly low-carbon fuels, and jeopardize the achievement of a 10% reduction in fuel CI by 2020.

The general process used by CARB to quantify the GHG emissions from LUC and to convert those emissions to a CI value that can be added to a fuel's direct CI value is illustrated in Figure 4.

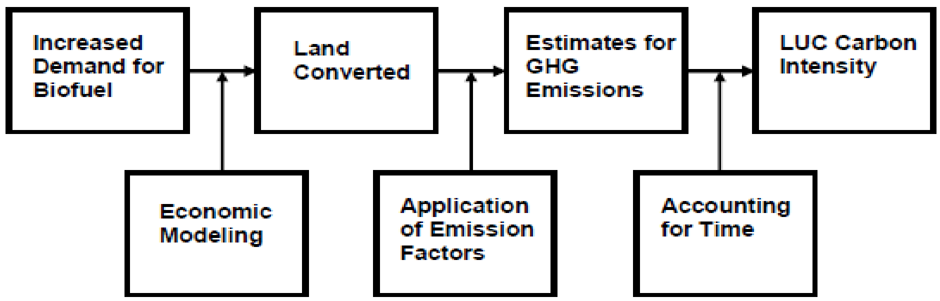

Figure 4: LUC Impact Estimation Process (CARB 2009).

Estimating how much non-agricultural land is converted to agricultural uses in response to increased demand for biofuels requires a model capable of simulating the multiple economic forces driving the LUC process. Models of the international agricultural system have been adapted to estimate the magnitude of biofuel-driven LUC impacts. The GHG emissions generated by the conversion of land to agricultural uses are estimated by applying emission factors to the acreage of land converted.

Emission factors are estimates of the GHGs released from each converted unit of land area. GHGs are released from burned or decomposing cover vegetation and disturbed soils. LUC emissions vary substantially with time and emission flows are converted to LUC carbon intensity using a time accounting method. Large initial releases of GHGs from clearing native vegetation are followed by slower releases from below-ground materials. The time-varying emission flows are converted to a LUC carbon intensity value using a time accounting model.

CARB has established two main approaches for determining the CI of fuels under the LCFS, both of which consider ILUC impacts. The first method is CARB "lookup tables" which include carbon intensity values for fuels as determined by the agency using its California-modified GREET model (with LUC modifiers when applicable). The other is "customized lookup tables" by which regulated parties may propose modifications to California-GREET model inputs, including new fuel pathways, to determine fuel specific carbon intensity values. The customized approach must be approved by CARB and meet necessary scientific criteria.

Conclusion

As noted previously, there are no existing internationally agreed methodologies or policy structures for dealing with ILUC impacts on GHG emissions from biofuels production and use. The need to improve datasets and modelling systems to more reliable determine ILUC and sustainability is recognized and work continues to effect these improvements. A global consensus on certification and sustainability criteria for biofuels would address many issues related to ILUC.

Other regions and countries are beginning to consider ILUC impacts within their own biofuels polices either already implemented or under development. For the most part, none of these countries has established specific legislative or regulatory requirements to include sustainability criteria and ILUC impacts within their biofuels programs. China, India, Malaysia and Philippines have established land use-related policies (detailed in Section 7) that provide guidance on how their lands can be developed for biofuel feedstock production, however these guidances are not build in relation to ILUC for biofuels use. As the expansion of formal legislative and regulatory programs on biofuels production and use occurs, more of these countries will incorporate ILUC impacts into their policy determinations and GHG emissions.

7. OTHER POLICY APPROACHES THAT ADDRESS BIOFUELS ILUC CONCERNS

As noted, policies that serve to address ILUC concerns are being or have been included in biofuels policies in the U.S. and the EU. Other countries have already taken or are taking different approaches that focus on land use management and promoting or requiring best agricultural practices. As noted, a number of countries have instituted specific land management policies to help ensure that biofuel development takes place on land which will not impact on biodiversity, social and economic needs, soil erosion, water conservation, labour rights and land rights. Moreover, governments have also taken steps to promote best agricultural practices which are environmentally sustainable as well as socially accepted and promote an efficient use of energy should negate the need for an ILUC factor. Best agricultural practices would include such practices as no-till farming, improving integration between agriculture and cattle operations, and phasing out pre-harvest field burning, which is currently practiced in some sugar cane growing countries.

This section provides examples of such policies set in countries such as Brazil, China, India, Malaysia and the Philippines. For these countries, biofuels are not only seen as a means to reduce energy dependence, but as a key mechanism to improve farmers' income and in some cases, improve remote communities' access to liquid fuels. While it is true that the setting of a particular policy is <u>much different</u> than ensuring that policy is implemented through an appropriate monitoring and/or enforcement scheme, it is important to note that countries are recognizing that there may be LUC issues related to biofuels production and use and that they are taking steps to address those issues. Many of these countries began addressing these issues before biofuels ILUC came to the fore.

At the outset, consider that there is a very different concept of land use between the western context and Asian context. In the Asian context, any land that is not used for food plantations will be considered as "safe" land to be used for biofuels. Although there is often no clear policy by Asian governments on their land use policies for biofuels, the Asian countries do not intend to use land that is still suitable for agricultural use to be converted to producing crops for fuel. Many stakeholders in Asia have difficulty accepting the concept of ILUC as they are dealing with very high population increase rate. Hence they will use any land they have for human settlement and food production which in the end contribute to the clearing of forests and peat lands.

Brazil

Brazilian President Lula announced a proposal in September 2009 to ensure sustainable expansion of sugar cane harvesting in Brazil while addressing sustainability and ILUC issues in the Brazilian sugar cane industry. In addition, the Brazilian Research Center for Agriculture (EMBRAPA) took over coordination of the Agro-Ecologic Zoning Program for sugar cane nationally. The results of the Zoning Program should be used as guidelines for licensing and financing decisions. The following aspects of the program are being considered in order to define adequate areas:

- Soil and weather adequacy;
- Topography;

- Water availability;
- Water requirements;
- Sugarcane cannot be planted in areas with sensible ecosystems;
- Areas where other crops have been produced.

Approximately 35 Mha would be declared adequate for sugar cane cropping. These areas are highly concentrated in the states where most sugar cane production already occurs, for example the states of São Paulo, Paraná and Minas Gerais. Another such program adopted in Brazil is the Verified Sustainable Ethanol Initiative. In May 2008, the Swedish company SEKAB together with Brazilian ethanol producers developed this program and verified and traceable ethanol has been available in Sweden since August 2008. The sustainability criteria put in place to meet EU and Swedish National law include, among other things, a specific provision concerning zero tolerance for felling rainforest and continuous monitoring provisions.

The Green Protocol of the State of São Paulo in 2007 establishes an early phase-out of sugar cane pre-harvest field burning (an old practice utilized to facilitate the manual sugar cane cutting): from 2012 to 2014 for mechanized areas and from 2013 to 2017 for steeper slopes. This protocol is a voluntary scheme with the goal of promoting best practices within the sugar cane industry. The São Paulo's government future target is to issue a Certificate of Conformity to producers adhering to this program.

According to the Association of Sugarcane Producers (UNICA), the elimination of straw burning will help reduce CO_2 emissions in 8.5 million tons over the 10-year period that the protocol is scheduled to last. It is important to note that more than 150 mills (approximately 85% of producers) and 13,000 suppliers have already committed to meet the goals established by the protocol. Mechanized areas in the state increased from 34% in 2007 to 53.8% during the 2009-2010 harvest, scheduled to end in May 2010. That means that more than half of the cane harvested in Brazil takes place without burning. By the 2010-2011 harvest, the state government expects to reach 70% of conformity.

In addition, there other initiatives currently being undertaken in Brazil to promote best agricultural practices, which are part of the Agro-Environmental Protocol, such as protection of riparian forests in sugar cane areas, soil conservation, implementation of water conservation programs, and recycling of solid wastes among others. Following the Green Protocol adopted by São Paulo, there are current discussions among other producing states, which are also willing to phase out sugar cane field burning before harvesting in their regions.

China

In China, the Ministry of Agriculture in 2007 released an Agricultural Biofuel Industry Plan (2007-2015), which aims to develop a number of new crop bases by 2010 to provide sufficient biomass resources to meet the country's growing demand for ethanol and biodiesel. The plan expected the new crop bases to mostly grow non-grain feedstock such as sugar cane, sweet sorghum, cassava and sweet potatoes as feedstock for ethanol production since they can be grown on non-arable land. Sweet sorghum was recommended to be cultivated on 10 million hectares of unused saline land located in the provinces of Heilongjiang, Shandong, Inner Mongolia, Xinjiang and Hebei. The plan estimated that an additional 13 million hectares of unused land is suitable for developing new cassava plantations in the provinces of Guangxi, Guangdong, Hainan, Fujian and Yunnan. The plan also recommended the expansion of sweet potato plantations in the provinces of Guangxi, Chongqing and Sichuan.

Some governments have put into place specific policies requiring or promoting the use of the use of idle, degraded, marginal, and/or waste land. Again, however, note there are no commonly accepted definitions of these terms. Nevertheless, the Chinese government have taken steps in this area. China's land use policy restricts biofuels production on crop land, and focuses on marginal or wasteland for growing feedstocks for producing bioethanol and biodiesel. For instance, in Southwest China, provincial governments have plans to plant jatropha on "barren land", i.e., land that is not suitable for agricultural use, in provinces such as Sichuan, Guizhou and Yunnan. The governments own some barren land which would be managed by government agencies if put to use; a significant amount of barren land is owned by village collectives, with use rights granted to individual households. In China, there are nearly 0.1 billion ha of marginal lands including saline, sandy, mining lands, etc., which can be used to plant energy crops.

India

India has also taken steps in this area. The National Policy on Biofuels was announced in September 2008 which was subsequently approved in December 2009. The policy aims to facilitate and bring about optimal development and utilization of indigenous biomass feedstocks for production of biofuels. The government's approach to biofuels is based solely on non-food feedstocks to be raised on degraded or wastelands that are not suited to agriculture. The focus for the development of biofuels in India will be to utilize waste and degraded forest and non-forest lands only for cultivation of shrubs and trees bearing non-edible oilseeds for production of biodiesel.

Plantations of trees bearing non-edible oilseeds in India will be taken up on government/community wasteland, degraded or fallow land in forest and non-forest areas. Contract farming on private wasteland could also be taken up and plantations on agricultural lands will be discouraged. In all cases pertaining to land use for the plantations, consultations would be undertaken with the local communities through Gram Panchayats/Gram Sabhas, and with Intermediate Panchayats and District Panchayat where plantations of non-edible oilseed bearing trees and shrubs are spread over more than one village or more than one block. State governments would also be required to decide on land use for plantation of non-edible oilseed bearing plants or other feedstocks of biofuels, and on allotment of government wasteland, degraded land for raising such plantations.

Jatropha is one of the most popular non-edible oilseeds used for biodiesel production in India. As India has nearly 60 million hectares of wasteland, the government has indicated that about 30 million hectares could be made available for plantations with an aim to producing a minimum of 2 tons (8,602 gallons) of biodiesel per year per hectare. This can be achieved through research on improving the productivity of jatropha oilseeds, mastering extraction and esterification technology, and finding profitable by products. According to the Ministry of New and Renewable Energy, 930,000 ha of wastelands were covered with jatropha and pongamia plantations in eight states as of February 2010.

Access to land is a fundamental importance in India especially in rural areas. It remains the principal determinant of rural income distribution. In the Indian context, in which a large and rising share of the rural poor derive livelihoods principally from their own labour, a powerful case can be made in favour of more equitable land distribution on the grounds that such a strategy would generate more employment than the alternative. In general, with the main objectives being to reduce poverty, raising agricultural productivity and promoting social inclusion, there are strong arguments for seeking ways to improve access to land for the poor and other socially excluded groups in rural India[1]. This will "eliminate" the need to follow ILUC concept.

Malaysia

The government of Malaysia has set a combination of policies described above that attempt to address sustainability concerns, including biofuels LUC, though there has been criticism of the

1 T. Haque, National Centre for Agricultural Economics and Policy Research, "Land Use Planning in India – Retrospect and Prospect."

government's lax enforcement of these policies. There is already a legislation regulating the sustainable development of the palm oil industry including the Land Acquisition Act 1960, Land Conservation Act 1960 (revised in 1989) and National Land Code 1965, Quality Act 1974 (Environmental Quality) (Prescribed Premises) (Crude Palm Oil) Regulation 1977.

The government has set a number of new initiatives to ensure sustainability and competitiveness of the oil palm industry. In August 2007, the Ministry of Plantation, Industries and Commodities launched the "Codes of Practices & Sustainability Manual." In addition to preparing a sustainability manual for the oil palm industry, the following five codes of practices were set:

- Good agricultural practice for oil palm estates and smallholdings;
- Good milling practice for palm oil mills;
- Good crushing practice for palm kernel crushers;
- Good refining practice for palm oil refineries;
- Good practice for the handling, transport and storage of products from the oil palm.

According to the Malaysian Palm Oil Council (MPOC), the Malaysian palm oil industry is supportive of addressing biofuels ILUC, but remains concerned about the issues such as the methodologies to analyse ILUC and the potential impact to developing rural economies. Though a diverse group of stakeholders have formed the Roundtable on Sustainable Palm Oil (RSPO) and adopted "Principles and Criteria for Sustainable Palm Oil Production" which in part addresses biofuels ILUC concerns, there has been public criticism of the lack of "teeth" in the RSPO principles.

The Philippines

The Biofuels Act of 2006 (Republic Act 9637) was formally signed into law on Jan. 17, 2007. The enactment of the Biofuels Act, which mandates the utilization of idle lands for feedstock production in the Philippines, led to the commissioning of the Department of Agriculture to formulate the Biofuels Feedstock Program. It has two subprograms including the Biodiesel Feedstock Program and the Bioethanol Feedstock Program, with implementation targeted within five years starting in 2007.

Through the Philippine Agricultural Development and Commercial Corporation (PADCC), the Department of Agriculture provides information on assistance in selecting ideal investment locations; joint venture matching; and facilitation of surveys, permits, and clearances to biofuel investors. As of 2008, 49 biofuel projects generated a total of 11,539 ha planted with various crops (8,887 ha for biodiesel and 2,652 ha for bioethanol). The program supports feedstock production through R&D such as varietal improvement of potential feedstock sources including seed production, planting materials, plantation development and postharvest technologies.

In December 2008, a Joint Administrative Order (JAO) No. 2008-1 was signed by various Philippine government agencies on the "Guidelines Governing the Biofuel Feedstocks Production, and Biofuels and Biofuel Blends Production, Distribution and Sale under Republic Act No. 9637." Also known as the Omnibus Guidelines on Biofuels, they basically provide guidance on screening and processing applications for certifications, licenses and permits to operate as a biofuel feedstock producer, biofuel and biofuel blend producer, distributor and reseller. One of the land use guidelines ensures that lands devoted to food crops shall not be utilized for biofuel feedstocks production.

The JAO specifies requirements for biofuel feedstock producers, where applicants are required to secure certification from the Department of Agriculture that the feedstock or the proposed biofuel feedstock area may be utilized for the production of biofuel feedstock. Certification is not required if the feedstock to be used (e.g. molasses) does not involve land utilization. The following are the criteria for the issuance of certification:

- Cereals that can be used both for food and for biofuel production such as, but not limited to, maize and wheat shall not be used for biofuel production;

- The land to be used shall be consistent with the natural expansion of the municipality or locality, as contained in the approved physical framework and land use plan by the concerned municipality or locality;
- The area that will be used is not the only remaining food production area of the community;
- All agricultural areas classified hereunder shall not be utilized for biofuel feedstock production:
  - All areas covered by government-funded irrigation facilities, either national agency or LGU, designed to support rice and other crop production, and all irrigated lands where water is not available for rice and other crop production but are within areas programmed for irrigation facility rehabilitation by the department of agriculture and the national irrigation administration (NIA);
  - All irrigable lands already covered by irrigation projects with firm funding commitments as certified by NIA at the time of the application for land use conversion;
  - All privately irrigated alluvial plain lands utilized for rice and maize production; and
  - All agricultural lands that are ecologically fragile, the utilization of which will result in serious environmental degradation.

The Department of Agriculture has listed in one of its conditions to evaluate that the areas are underutilized and marginal before issuing the certification. Independent biofuel feedstock producers (i.e. has no marketing or supply agreement with a biofuel producer) with effective areas of less than 25 hectares are exempted from securing the certification. On the other hand, biofuel producers which hold agricultural lands as biofuels are required to apply to the Department of Agriculture's National Technical Committee on Land Use Matters (NTECLUM) to secure the Certification of Eligibility for Reclassification of Agricultural Lands.

Conclusion

A number of countries are sensitive to biofuels LUC. While these countries have not followed the lead of the U.S. and EU in biofuels ILUC policy setting, these countries have been addressing LUC by putting into place legislation and/or regulations that require specific land use management practices for biofuels feedstocks. Moreover, they have taken steps to address the issue by promoting and/or requiring best agricultural practice. Notably, many of these countries began to consider these issues before they became a popular point of discussion in the biofuels realm and before some industry-lead initiatives gained popularity and focus. Some countries have put into place ambitious policies in this area but effective enforcement of these policies is lacking.

We note also that a number of voluntary initiatives have emerged in addition to the RSPO, highlighted above. Many of the sustainability criteria and principles contained within other voluntary initiatives such as the Roundtable for Sustainable Biofuels (RSB), Roundtable on Responsible Soy Association (RTRS), Better Sugar Cane Initiative (BSI) include concepts that in effect address biofuels LUC as well. However, with the exception of the BSI none of the schemes have addressed directly biofuels ILUC, preferring instead to concentrate among other things on best practice within land management, biodiversity, water resources and human social and economic rights

The BSI has applied to the EU Commission for voluntary scheme recognition. To qualify for EU recognition under RED section 6, the basis for the calculation of GHG emissions and the protection of land with high biodiversity value must be presented. Section 6 does not currently allow for actual values to be used when calculating the greenhouse gas emissions from the production and use of sugarcane ethanol. This may be changed in future revisions. To calculate emissions the default values in annex V of the RED must be used. GHG emissions resulting from changes in land carbon stocks must be added to the default values.

The RSB recognizes the effect of both biofuels DLUC and ILUC, and Principle 3 of the standard – Greenhouse Gas Emissions – makes reference to this when calculating the lifecycle GHG emissions of the feedstock or biofuel. In June 2010 at a RSB workshop held in Rio de Janeiro it was agreed by the majority of participants that the RSB should continue to review indirect impacts of biofuels, however no consensus was reached as to how this should be reflected in its Standards. When discussing indirect impacts at the project level, the majority opinion was that an ILUC factor was not a good option and that more emphasis should be placed on "qualitative approaches". It was suggested that a differentiation be made among feedstocks based on regional differences and that feedstocks be classified according to their risk level for indirect impacts.

8. ILUC AND POTENTIAL IMPLICATIONS FOR THE EMERGING GLOBAL BIOFUELS MARKET

Biofuels supply and demand is expected to grow in the coming years. By 2020, total demand for biofuels in the four major producing and consuming regions of North America, Latin America & Caribbean, EU and Asia-Pacific may reach 249.4 billion liters (65.8 billion gallons). Ethanol demand will represent the overwhelming majority of this demand at 73%, representing 184 billion liters (48.6 billion gallons) and may represent 13% by volume of the global gasoline pool by 2020 (Hart 2010). Biodiesel demand will continue to increase, but more modestly, representing 6% of the on-road diesel pool comprising the aforementioned four regions, or 65.3 billion liters (17.25 billion gallons), by 2020 (Hart 2010). Africa is expected to contribute very modestly to both biofuels supply and demand through this time period.

The effect of ILUC on the emerging global biofuels market is potentially expected to be two-fold: first as ILUC policies may prevent the use of some feedstocks in large markets and demand for other, more sustainable biofuels will rise. The biofuels that are linked to ILUC concerns may find markets in other countries that are now only starting their biofuels policies but are not as concerned by biofuels ILUC issues. More than 39 countries either have or are scheduled to implement biofuels mandates in 2010 and the majority of those are in developing countries which have not expressed concerns about biofuels ILUC. This section will first review the expected supply and demand of ethanol and biodiesel until 2020 with some ILUC considerations, and then, the impact of ILUC on the expected biofuels trade flows both to countries which have ILUC policies in place, and those which do not.

Ethanol Outlook to 2020

Ethanol is the main biofuel currently used worldwide with the two main producers and consumers being Brazil and the U.S. Ethanol is expected to remain the main biofuel used and the main supplier of ethanol on the international market until 2020 is expected to be Brazil by an overwhelming margin. The main parameter expected to affect ethanol trade flows in the near future is the sustainability criteria that have been used in biofuels policies in the U.S. (RFS2) and California (LCFS) and in the EU (RED and FQD). By attributing high GHG-saving potential to Brazilian ethanol specifically, these policies are expected to create high demand for this product, which in turn could affect other ethanol and sugar-producing countries, thus leading to potential ILUC concerns. The analysis hereafter shows the expected trends in the ethanol market worldwide considering four main biofuel-producing regions: Asia Pacific, EU27, Latin America and North America. Ethanol supply and demand projection until 2015 by region is presented in Figure 5. It shows that the Western Hemisphere, lead by the U.S. and Brazil, will continue to represent about 86% of global ethanol production and nearly 80% of consumption through 2020.

As figure 5 shows, there will be some supply growth in the Asia-Pacific region by 2020, which will represent 10% of global ethanol production by then. EU-27 supply growth over by 2020 is quite modest as traditionally only 50% of capacity has been used and is reported in this forecast. On the demand side, the EU currently imports around 1.5 billion litres of ethanol mainly from Brazil (2009 and 2010). This figure is expected to double by 2020 to nearly 4 billion litres.

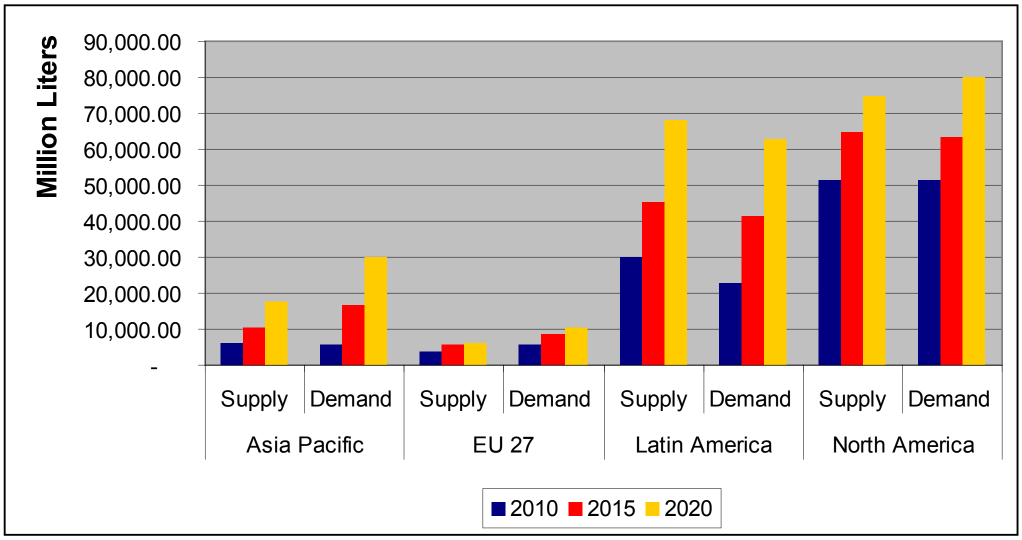

Figure 5: Ethanol Supply and Demand by Region, 2010-2020 (Hart 2010).

On the supply side, ethanol is expected to be only first generation ethanol until at least 2015, in spite of research efforts and funds being allocated to cellulosic ethanol so as to allow the use on non-food, non-ILUC and high GHG emission savings ethanol (Hart 2009). Cellulosic ethanol projects are not expected to produce large enough commercial volumes by 2015 to satisfy requirements in countries such as the U.S. This is one of the main drivers for Brazilian ethanol imports, as the GHG saving potential associated with it is high and Brazilian ethanol is even considered an advanced biofuel in the U.S. under the RFS2 program. Demand for Brazilian ethanol is expected to grow substantially in the U.S. and in particular in the state of California.

Essentially, sugar cane ethanol from Brazil is the only commercially available, economical biofuel available to meet RFS2 advanced biofuel requirements. In California, it has been estimated that at least 50% of the state's ethanol demand could be satisfied with Brazilian ethanol (Hart 2009). The growth in sugarcane ethanol demand is directly due to the LCFS which takes effect in 2011. Total Brazilian ethanol demand in the U.S. could reach 5.7 billion litres (1.5 billion gallons) by 2015. By 2020, Brazil will be in position to export a minimum 11 billion litres (approximately 3 billion gallons) to the world market, in particular, the U.S., Europe, Japan and possibly China. Meantime, internal ethanol demand in Brazil is expected to continue to climb as well.

Biodiesel Outlook to 2020

Biodiesel is a distant second after ethanol in terms of global biofuels supply and demand. Nevertheless, palm oil cultivation in South East Asia linked to biodiesel production has helped to trigger the debate on ILUC when it was shown that new plantations were started on cleared tropical forest land even if forest clearing has been mainly linked to timber production. A similar situation has been found in Latin America, in particular in Brazil, where it was charged that soy oil plantations were encroaching on the Amazon forest and then led to the soy moratorium in Brazil. As a result, an ILUC factor in biofuels policies around the world may well affect biodiesel feedstocks and the biodiesel market perhaps more than it is expected to affect the ethanol market.

Figure 6 shows the expected biodiesel market evolution until 2020 in four regions: Asia Pacific, EU27, Latin America and North America. The analysis does not take directly ILUC into consideration and the impact of ILUC is discussed following the business as usual case presented hereafter.

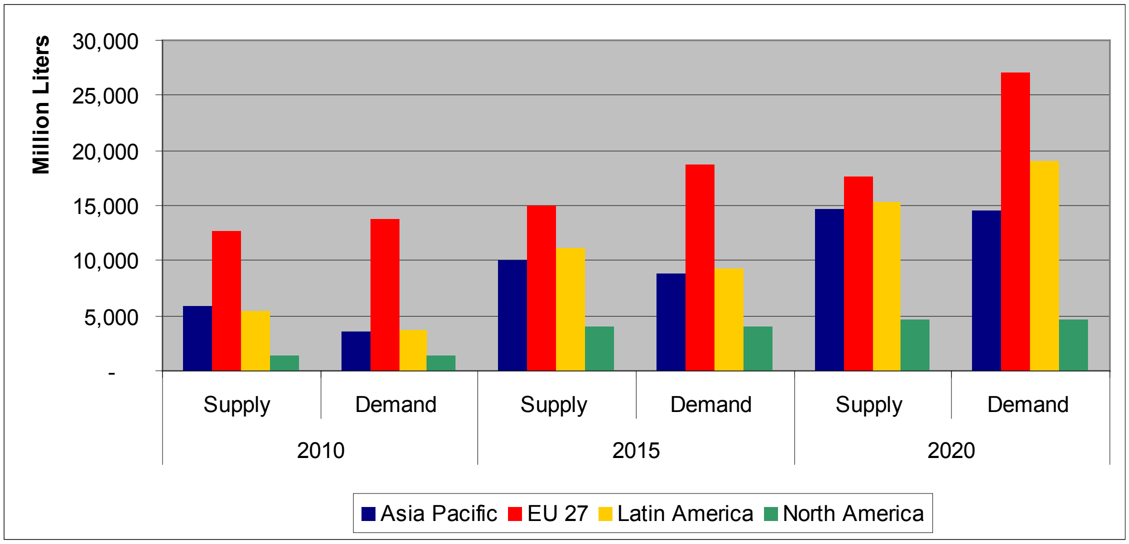

Figure 6: Biodiesel Supply and Demand by Region, 2010-2020 (Hart 2010).

As can be seen in Figure 6, with respect to biodiesel, Europe currently dominates consumption representing about 61% of global consumption in 2010. The region also represents 50% of supply. However, significant growth in supply and demand is expected to come from the Asia-Pacific and Latin American regions. Combined, these two regions are projected to overtake Europe by 2020 and represent about 51% of global biodiesel demand.

For 2010 and even 2015, the increase in capacity will lead to similar utilization rates even if consumption actually increases because of higher mandate levels. The EU relies mainly on rapeseed as biodiesel feedstock, although high prices have led the region to look at cheaper oils such as soy and palm oils as biodiesel feedstocks. Should the RED include an ILUC factor it would therefore affect the potential of the region to import these oils or biodiesel.

Global biodiesel supply will have to double over the 2010-2020 timeframe to accommodate demand requirements that governments around the world are aiming to implement. With biodiesel overcapacity an issue globally, producers in other countries complaining about cheap imports and with policies structured that tend to disfavor imports altogether, many countries will focus on their own internal markets. For example, the governments of Brazil and Argentina are likely to increase biodiesel blending limits to absorb excess capacity and will supply their respective internal markets. Many of these countries do not address biofuels ILUC in their biodiesel policies at this time.

As previously discussed, palm oil is the feedstock most closely associated with potential ILUC issues. Recent studies give ILUC values for palm oil of 74 kg/GJ to 153 kg/GJ for 20 years of depreciation, compared to lower or negative values for rapeseed, wheat, corn or sugar beet. Soy however has been attributed a very high ILUC factor in one study of 166 kg/GJ. The ILUC values should not hide the fact that palm is a very efficient plant with a very high oil yield. Should ILUC factors lead palm oil and palm oil based biodiesel from Indonesia and Malaysia to fail the EU and U.S. sustainability criteria after 2011, then the 2015 biodiesel supply and demand scenario would be severely affected. By then, potentially 20.1 billion litres (5.3 billion gallons) oversupply of biodiesel from Indonesia and Malaysia would be without value for the EU and U.S. biofuels targets. As mentioned earlier, the U.S. is not expected to need large quantities of feedstock or biodiesel imports from outside since the soybean biodiesel GHG factor has been found to meet the minimum GHG criteria under the RFS2 program.

In the EU, the expected biodiesel demand in 2015 is close to 18.8 billion litres (5 billion gallons) and the EU biodiesel capacity should exceed that demand at 26.5 billion litres (7 billion gallons). In spite of the fact that the EU has enough capacity to meet its demand, biodiesel is imported into the EU. Biodiesel from the U.S., Argentina and South East Asia has been imported into Europe due to economic considerations as local rapeseed oil or rapeseed biodiesel was more expensive than imports. By 2015 supply of biodiesel from the EU should be around 15 billion litres (4 billion gallons) therefore leading to 3.8 billion litres (1 billion gallon) of imports. However by 2015 the 38% GHG saving default value achieved by rapeseed biodiesel will be struggling to meet the 2017 target of 50% minimum GHG reduction under the RED unless the value has been improved through advances in rapeseed LCA or the FAME from rapeseed production process.

The EU biodiesel producers could therefore have to look at alternative feedstocks. However as the GHG saving default values stand now, both palm oil and soybean oil appear to have worse GHG savings than rapeseed oil, unless there is methane capture at the oil mill in the case of palm oil. The fact that the palm oil GHG saving factor has been revised in the U.S. could lead to a revision in the EU too. Considering the existing GHG saving factors, the potential biodiesel feedstocks meeting the 50% cut would be sunflower oil, palm oil with methane capture at the oil mill and tallow or other wastes. The fact that palm oil could face ILUC issues and not be available to the EU could therefore severely affect the potential of the EU to meet its biofuels mandate under the RED.

A side effect of the ILUC factor preventing or limiting palm oil from being used in the EU biodiesel industry could be the increase in the use of ethanol in the EU. As the mandate for biofuels would still be in place for 2020 Member States could meet their obligation with more ethanol and less biodiesel. This in turn would put pressure on the ethanol producing countries and could potentially lead to ILUC in ethanol exporting countries. In addition, Hart sees as highly probable the creation of a biofuels market between developing countries, thus by-passing the EU and U.S. where ILUC factors would be implemented. Palm biodiesel from Malaysia and Indonesia could be used in the countries where it is produced, with no ILUC limitation, but could also be exported to other large markets where there are no ILUC considerations such as China. In that case, the introduction of ILUC factors in the EU and U.S. would fail to meet its purpose.

Another region which could be affected by the introduction of ILUC factors applied to biofuels is Africa. There are for now over 27 African countries where biofuels projects have been launched or announced and the targets are both the internal and exports markets as shown in Figure 7. The countries that plan on exporting biofuels are generally looking at the EU as an export market.

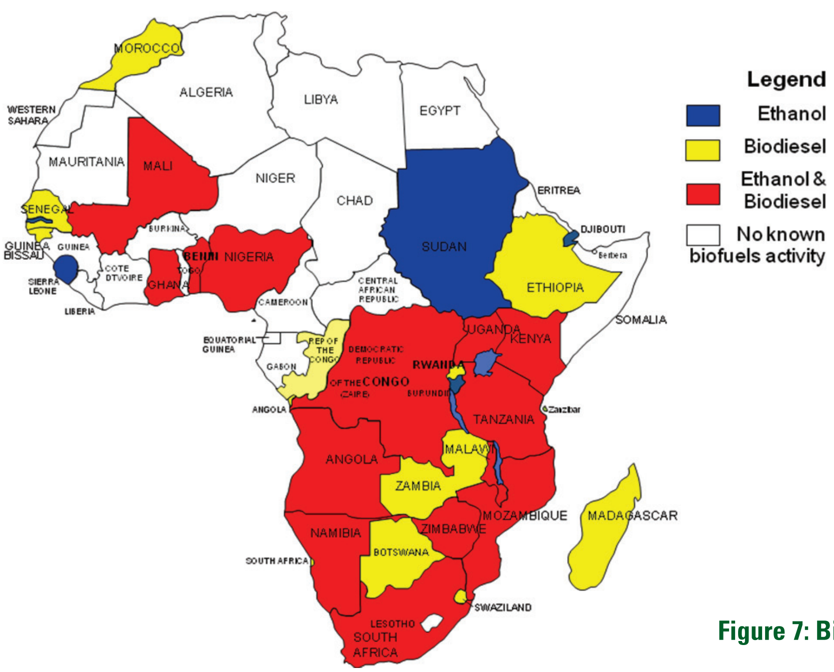

Figure 7: Biofuels Projects in Africa (Hart 2010).

This is because of historical links as well as tax benefits. The restriction of exports in other biofuel producing regions could potentially affect biofuels projects in Africa by creating more demand for biofuels from the region. However there are also reports of unsustainable land developments associated with biofuels plantations in Africa and ILUC issues too. It is therefore quite unsure whether the continent would be able to supply the shortfall of biodiesel demand or extra ethanol demand from the EU should other regions be unsuitable feedstock providers due to ILUC concerns. As in Asia, African countries could look for other biofuels markets where to sell their production, thus bypassing ILUC issues.

9. CONCLUSION: BALANCING THE RISKS AND UNCERTAINTIES

It is clear from this review that multiple uncertainties exist about a wide range of factors in assessing biofuels ILUC: true land availability, yields, GHG savings, net energy savings, direct environmental effects and potential market impacts and unintended consequences of biofuels ILUC penalties or factors. All these affect the amount of DLUC and ILUC and make accurate projections extremely unlikely and hence any economic decisions extremely risky. Permutations and combinations of LUC are endless and their drivers are many and interrelated. Given high uncertainty, there is much variation in outputs between different models due to errors and differences in input data, digital maps and remote sensing interpretation and how well algorithms included in the model express important processes and simulate dominant LUC. There is even general uncertainty in predicting future LUC decisions involving human free will and behaviour.

Lohmann (2006) raised some important points about risk and uncertainty by recalling the seminal work of the great 20th century economist Frank Knight's *Risk, Uncertainty and Profit* (1921). Knight is famous for his distinction between risk and uncertainty, which Lohmann expands as follows:

Risk in Knight's sense refers to situations where the probability is well known, e.g. flipping a coin. Such known risk factors in biofuels, we suggest are currently few.

Uncertainty is different: you know the things that can go wrong, but cannot calculate the probability, e.g. the effects of weather on yields over the next few years.

Ignorance is again different: these are the unknown unknowns, and ILUC is a case in point, of something that was largely unknown and is now perhaps in the process of becoming "uncertain".

Finally there is *indeterminacy* where the probability of a result cannot be calculated because it is not a matter of science, modelling and prediction, but of decision. Hence future political decisions cannot be easily guessed and so not factored into calculations. Currently this is a major problem for the private sector, which requires clear signals about government direction on climate change, carbon prices and much else, in order to make important investment decisions. In such cases, Lohmann suggests that even trying to assign a probability to an outcome can affect the likelihood of the outcome itself. Risk fits easily into economic thinking, because it can be easily measured. Uncertainty, ignorance and indeterminacy however call for a more precautionary and flexible, less numerical approach. To date in the case of biofuels, the subject has not been noted for a precautionary approach. Lohmann cautions that by mixing up the analytically distinct concepts outlined above, risks blundering into what Knight would call a 'fatal ambiguity'.

The complexities of biofuels ILUC can be appreciated from the flow diagram (Figure 8) as well as the centrality of land use issues. To each of the boxes can or should be attached estimates of risk, uncertainty and indeterminacy, which we believe are largely lacking and need to be assessed if we are to truly assess the future of biofuels and their indirect effects.

Quite simply, the policy and market development of biofuels have proceeded so quickly over the last decade that the science needed to untangle the complexities of biofuels ILUC and address the uncertainties pointed out above has been outpaced. Biofuels will be an important tool for many countries as they begin to diversify their energy portfolios in this century and it is important

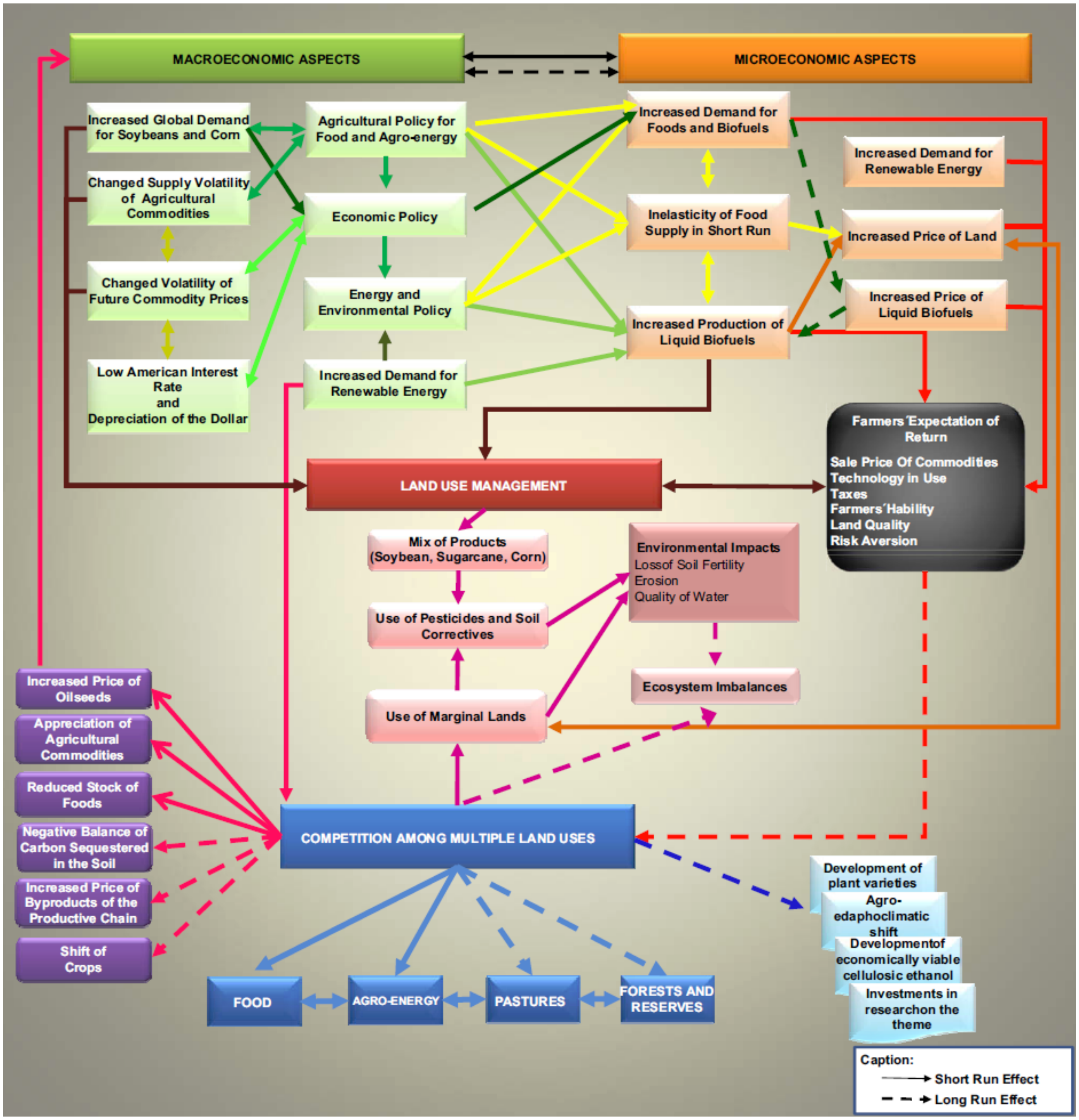

Figure 8: Analytical framework for the analysis of the cause and effect relations of land use competition (from Rathmann et al 2010).

to note that not all biofuels and biofuels feedstocks are created equally. We hope that the many uncertainties raised in this paper do not detract the reader from contemplating the serious issues that biofuels LUC present. The switch away from fossil fuels to renewable alternatives will have unforeseen consequences, especially for highly populated resource-poor countries and presently the role of biofuels in this process is very unclear.

We end this review with a list of knowledge gaps that need addressing and some suggestions for stakeholders:

1. **More experimentation and modelling:** It is clear that there are several aspects of biofuel production that work against the very goals policies are trying to achieve – reduction of GHGs and protection of scarce and valuable natural resources. These need to be very carefully elucidated by monitoring, experimenting and modelling in many locations around the planet.

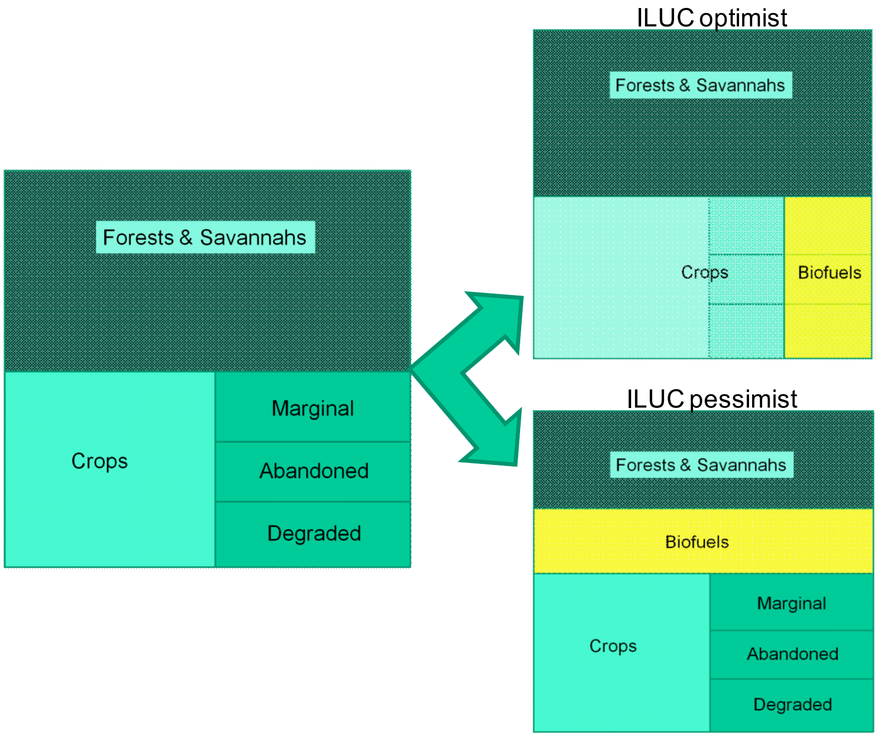

Figure 9: The two extremes of the ILUC debate (after Bauen and Howes in Woods, 2009).

2. **Establish standard methodologies to evaluate LUC from biofuels:** It is very clear that there are major site-specific effects of biofuel-related agriculture which may explain some of the differences between different published papers, but even so, the extent of ranges displayed (Figure 9) suggests major methodological differences. There should now be a major effort to establish reliable standard methodologies to be followed at the experimental and pilot scale to fully evaluate the wide range of effects, direct and indirect, that ensue from growing biofuels. This would enable much greater confidence when comparing future studies and greatly enable decision makers to make more informed judgments.
3. **Quantify available marginal land:** Marginal, abandoned, degraded and unused lands are really the only possible sources of significant land for biofuel expansion. They are often invoked but rarely quantified. How much of each exists in each region? What are the problems to be overcome to bring these lands into production?
4. **Establish effective land use management and best agriculture practice policies for biofuels feedstock crops:** It is not clear whether ILUC factors or penalties in biofuels programs will ultimately be successful. More useful may be establishing land use management and best agricultural practice policies in conjunction with biofuels programs which some countries are already doing and as described in Section 7.

We also suggest that experts continue to convene to discuss these issues and work toward establishing methodologies that will further help illuminate the complex issues surrounding biofuels ILUC. The development of a knowledge product or tool kit to help regulators in countries plan rationally for the future may be advisable as well.

We conclude with a final thought:

"*Upon this handful of soil our survival depends. Husband it and it will grow our food, our fuel, and our shelter and surround us with beauty. Abuse it and the soil will collapse and die, taking humanity with it*". [The Vedas Sanskrit Scripture 1500 BC]

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REFERENCES

Achten W M J, Verchot L, Franken Y J, Mathijs E, Singh V P, Aerts R, Muys B (2008) Jatropha bio-diesel production and use. *Biomass and Bioenergy* 32, 1063-1084.

Achten W, Maes W, Aerts R, Verchot L, Trabucco A, Mathijs E, Singh V, Muys B (2010) Jatropha: From global hype to local opportunity. *Journal of Arid Environments* In Press.

Aide T M, Zimmerman J K, Rosario M, Marcano H, Walker L R, Silver W L, Willig M R, Zimmerman J K (1996) Land-use dynamics in a post-agricultural Puerto Rican landscape (1936-1988). *Biotropica* 4A, 525-536.

Ariffin D, Idris A S, Singh G (2000) Status of Ganoderma in Oil Palm. In 'Ganoderma Diseases of Perennial Crops' (eds J Flood, P D Bridge and M Holderness) CABI Publishing, Wallingford, UK. http://bookshop.cabi.org/

Aubréville A (1938) La forêt coloniale: Les forêts de l'Afrique Occidentale Française, Annales d'Académie des Sciences Coloniales, IX. Société d'Editions Géographiques, Maritimes et Coloniales, Paris.

Aubréville A (1949) Climats, Forets et Desertification de l'Afrique Tropicale; Geographie Maritime et Coloniale. Paris, 351.

Balesdent J, Chenu C, Balabane M (2000) Relationship of soil organic matter dynamics to physical protection and tillage. *Soil and Tillage Research* 53, 215-230.

Bassett T, Koli Bi Z (2000) Environmental discourses and the Ivorian savanna. *Annals of the Association of American Geographers* 90, 67-95.

Berg S (1997) Some aspects of LCA in the analysis of forestry operations. *Journal of Cleaner Production* 5, 211-217.

Binswanger H P and McIntire J (1987) Behavioral and material determinants of production relations in land abundant tropical agriculture. *Economic Development and Cultural Change* 36, 73-99.

Boddey R M, Aves B J R, Urquiaga S, Fisher M (2002) Potential for carbon accumulation under Brachiaria pastures in Brazil. In Kimble J, Lal R, Follet R (eds) *Agriculture practices and policies for carbon sequestration in soil*. Advances in Soil Science Series, CRC Press, Boca Raton, Florida. http://www.crcpress.com/

Bondeau A, Smith P C, , Zaehle S, Schaphoff S, Lucht W, Cramer W, Gerten D, Lotze-Campen H, Müller C, Reichstein M, Smith W B (2007) Modelling the role of agriculture for the 20th century global terrestrial carbon balance. *Global Change Biology* 13, 679-706.

Boserup E (1965). The conditions of agricultural growth. The economics of agrarian change under population pressure. George Allen and Unwin, London. http://www.routledge.com

Brittaine R, Lutaladio N (2010) Jatropha: A smallholder bioenergy crop - the potential for pro-poor development. Integrated Crop Management Vol. 8. 1-114, FAO. http://www.fao.org/docrep/012/i1219e/i1219e00.htm

Bruinsma, J (2003) World agriculture: towards 2015/2030. An FAO perspective. Earthscan, London. http://www.fao.org/docrep/005/y4252e/y4252e00.htm

Bryant D, Nielsen D, Tangley L (1997) The last frontier forests: ecosystems and economies on the edge. World Resources Institute, Washington DC. http://www.globalforestwatch.org/english/pdfs/Last_Frontier_Forests.pdf

Burney J A, Davis S J, Lobell, D B (2010) Greenhouse gas mitigation by agricultural intensification. *Proceedings of the National Academy of Sciences* 107, 12052-12057.

Cadisch G, Giller K (2001) Soil organic matter management: The role of residue quality in C sequestration and N supply. In: *Sustainable Management of Soil Organic Matter*. Eds R M Rees, B C Ball, C D Campbell and B A Watson. 97-111. CAB International, Wallingford, UK. http://bookshop.cabi.org/

California Code of Regulations, Title 17, Chapter 1, Subchapter 10, Article 4, Subarticle 7 – Low Carbon Fuel Standard, 1 January 2010, http://www.arb.ca.gov/regact/2009/lcfs09/finalfro.pdf.

Campbell J E, Lobell D B, Genova R C, Field C B (2008) The global potential of bioenergy on abandoned agricultural lands. *Environmental Science & Technology* 42, 5791-5794.

Cherubini F (2010) GHG balances of bioenergy systems – Overview of key steps in the production chain and methodological concerns. *Renewable Energy* 35,1565–1573.

Chevalier A (1909) Les massifs montagneux du nord-ouest de la Côte d'Ivoire. *La Géographie* 20, 207-224.

Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007) Climate change 2007 – impacts, adaptation and vulnerability. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds. Cambridge University Press, Cambridge, UK, 976 pp http://www.cambridge.org/

Cotula L, Vermeulen S, Leonard R, Keeley J (2009) Land grab or development opportunity? Agricultural investment and international land deals in Africa IIED/FAO/IFAD, London/Rome. ISBN: 978-1-84369-741-1 http://www.fao.org/docrep/011/ak241e/ak241e00.htm

Coulter J K (1992) Population pressures, deforestation and land in the wet tropical forest zones: the technical dimension. In: Gregerson H, Gram P, Spears J (eds) Priorities for forestry & agroforestry policy research. pp 33-53. International Food Policy Research Institute, New York, USA. http://www.ifpri.org/publication/priorities-forestry-and-agroforestry-policy-research

DBCCA (2009) DB Climate Change Advisors. Investing in agriculture: far-reaching challenge, significant opportunity. http://www.dbcca.com/research

Demont M, Jouve P, Stessens J, Tollens E (2007) Boserup versus Malthus revisited: Evolution of farming systems in northern Côte d'Ivoire. *Agricultural Systems* 93, 215–228.

Dijkstra F A, Hobbie S E, Knops J M, Reich P B (2004) Nitrogen deposition and plant species interact to influence soil carbon stabilization. *Ecology Letters* 7, 1192–1198.

Dijkstra F A, Hobbie S E, Reich P B, Knops J M (2005) Divergent effects of elevated CO2, N fertilization, and plant diversity on soil C and N dynamics in a grassland field experiment. *Plant and Soil* 272, 41–52.

Doumenge C, Garcia Yuste J-E, Gartlan S, Langrand O, Ndinga A (2001) Conservation de la biodiversité forestière en Afrique Centrale Atlantique : Le réseau d'aires protégées est-il adéquat ? *Bois et Forêts des Tropiques* 268, 5-27. http://bft.revuesonline.com/

European Commission, Environment Directorate-General (2009) Terms of Reference for the Indirect LUC Impact of Biofuels http://ec.europa.eu/environment/air/transport/pdf/DG%20TRADE%20GEM.pdf.

Fairhead J, Leach M (1994) Contested forests: modern conservation and historical land use in Guinea's Ziama reserve. *African Affairs* 93, 481-512. http://afraf.oxfordjournals.org/content/93/373.toc

Fairhead J, Leach M (1996) Misreading the African landscape: society and ecology in a forest-savanna mosaic. Cambridge University Press, Cambridge/New York. http://www.cambridge.org/

FAO (1995) World Agriculture: Towards 2010. An FAO Study. Rome. http://www.fao.org/docrep/v4200e/v4200e00.htm

FAO (1997) State of the World's Forests. Oxford, UK. http://www.fao.org/docrep/w4345e/w4345e00.htm

FAO (2009) The state of food insecurity in the world. Economic crises: impacts and lessons learned; Rome, FAO, 56 pp.
http://www.fao.org/publications/sofi/en/

Fargione J E, Hill J, Tilman D, Polasky S, Hawthorne P (2008) Land clearing and the biofuel carbon debt. *Science* 319, 1235-1238.

Farrell A E, Plevin R J, Turner B T, Jones A D, O'Hare M, Kammen D M (2006) Ethanol can contribute to energy and environmental goals. *Science* 311, 506-508.

Finnveden G, Hauschild M Z, Ekvall T, Guinée J, Heijungs R, Hellweg S, Koehler A, Pennington D, Suh, S W (2009) Recent developments in Life Cycle Assessment. *Journal of Environmental Management* 91, 1-21.

Fischer G, van Velthuizen H T, Shah M M (2002). Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and Results. International Institute for Applied Systems Analysis, Laxenburg, Austria and FAO, Rome. http://www.iiasa.ac.at/Admin/PUB/Documents/RR-02-002.pdf

Fitzherbert E B, Struebig M J, Morel A, Danielsen F, Bruehl C A, Donald P F, Phalan B (2008) How will oil palm expansion affect biodiversity? *Trends in Ecology and Evolution* 23, 538-545.

Francis G, Edinger R, Becker K (2005) A concept for simultaneous wasteland reclamation, fuel production, and socio-economic development in degraded
areas in India: need, potential and perspectives of Jatropha plantations. *Natural Resources Forum* 29, 12–24.

Garcia-Quijano J, Peters J, Cockx L, van Wyk G, Rosanov A, Deckmyn G, Ceulemans R, Ward S, Holden N, Van Orshoven J, Muys B (2007) Carbon sequestration and environmental effects of afforestation with *Pinus radiata* D. Don in the Western Cape, South Africa. *Climatic Change* 83, 323-355.

Gerbens-Leenes W, Hoekstra A Y, Meer van der T H (2009) The water footprint of bioenergy. *Proceedings of the National Academy of Sciences* 106, 10219–10223.

Giampietro M, Mayumi K (2009) The Biofuel Delusion. Earthscan, London, Sterling V. A. http://www.earthscan.co.uk/

Gibbs H K; Ruesch A S; Achard F; Clayton M K; Holmgren P; Ramankutty N; Foley J A (2010) Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. Proceedings of the National Academy of Sciences 107, 16732–16737. doi: 10.1073/pnas.0910275107

Gnansounou E, Dauriat A, Panichelli L, Villegas J (2008). Energy and greenhouse gas balances: biases induced by LCA modelling choices. *Journal of Scientific & Industrial Research* 67, 885-897. http://nopr.niscair.res.in/bitstream/123456789/2418/1/JSIR%2067%2811%29%20885-897.pdf

Goetze D, Hoersch B, Porembski S (2006) Dynamics of forest–savanna mosaics in north-eastern Ivory Coast from 1954 to 2002. *Journal of Biogeography* 33, 653–664.

Grandin G (2009) Fordlandia: The Rise and Fall of Henry Ford's Forgotten Jungle City, Metropolitan Books. http://us.macmillan.com/metropolitan.aspx

Green D (2010) Sustainability Criteria Initiatives, Global Biofuels Center. http://www.globalbiofuelscenter.com/

Grieg-Gran M (2006) The cost of avoiding deforestation. Report prepared for the Stern Review of the Economics of Climate Change. International Institute for Environment and Development, London, UK. http://www.iied.org/pubs/pdfs/G02489.pdf

Hall C A S, Balogh S, Murphy D J R (2009) What is the minimum EROI that a sustainable society must have? *Energies* 2, 25-47.

Hammerschlag R (2006) Ethanol's return on investment: a survey of the literature 1990–present. *Environmental Science & Technology* 40, 1744–1750.

Haugen H M (2010). Biofuel potential and FAO's estimates of available land: The case of Tanzania**.** *Journal of Ecology and the Natural Environment* 2, 30-37. http://www.academicjournals.org/jene/PDF/Pdf2010/March/Haugen.pdf

Heanes D L (1984) Determination of organic C in soils by an improved chromic acid digestion and spectro-photometric procedure. *Communications in Soil Science and Plant Analysis* 15, 1191-1213.

Heller J (1996) Physic Nut – Jatropha curcas L. – Promoting the Conservation and Use of Underutilized and Neglected Crops. PhD dissertation, Institute of Plant Genetic and Crop Plant Research, Gatersleben, Germany & International Plant Genetic Resource Institute, Rome, Italy. http://tinyurl.com/cg2pw8.

Hennenberg K J, Goetze D, Minden V, Traoré D, Porembski S (2005) Size-class distribution of ***Anogeissus leiocarpus*** (Combretaceae) along forest–savanna ecotones in northern Ivory Coast. ***Journal of Tropical Ecology*** 21, 273-281.

Hoekstra A Y, Chapagain A K (2007) Water footprints of nations: water use by people as a function of their consumption pattern. ***Water Resources Management*** 21, 35–48.

Houghton R A (2003) Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management. *Tellus B* 55, 378–390.

House J I, Prentice I C, Ramankutty N (2003) Reconciling apparent inconsistencies in estimates of terrestrial CO_2 sources and sinks. *Tellus Series B, Chemical and Physical Meteorology* 55, 345–363.

Ickowitz A (2006) Shifting cultivation and deforestation in tropical Africa: critical reflections. *Development and Change* 37, 599–626.

Intergovernmental Panel on Climate Change (2000) Special Report on Land Use, LUC, and Forestry. Intergovernmental Panel on Climate Change. Geneva, Switzerland. Cambridge University Press. http://www.cambridge.org/

IEA Bioenergy (2009) Bioenergy – The Impact of Indirect LUC. Summary and conclusions from the IEA Bioenergy ExCo63 Workshop. Website http://www.ieabioenergy.com/DocSet.aspx?id=6214&ret=lib.

IEA World Energy Outlook (2009). http://www.worldenergyoutlook.org/

IEA Bioenergy task38 (2009) Workshop Report: LUCs due to Bioenergy: Quantifying and Managing Climate Change and Other Environmental Impacts, http://ieabioenergy-task38.org/workshops/helsink09/Task38_Helsinki_workshop_summary_final.pdf.

International Water Management Institute (2008) Water implications of biofuel crops: understanding tradeoff and identifying options. IWMI Water Policy Brief 30, 4 pp. http://www.iwmi.cgiar.org/Publications/Water_Policy_Briefs/PDF/WPB30.pdf

Johnston M, Foley J A, Holloway T, Kucharik C, Monfreda C (2009) Resetting global expectations from agricultural biofuels. *Environmental Research Letters* 4, 1-9. http://iopscience.iop.org/1748-9326/4/1/014004/pdf/erl9_1_014004.pdf

Kampman B, Brouwer F, Schepers B (2008) Agricultural land availability and demand in 2020. A global analysis of drivers and demand for feedstock, and agricultural land availability. *CE-Publications* No. 08.4723.29, CE Delft, Netherlands.

Kim H, Kim S, Dale B E (2009) Biofuels, land use change, and greenhouse gas emissions: some unexplored variables. *Environmental Science & Technology* 43, 961-996.

Klein T, Soares-Pinto M, Li H, Kosaka L, Steiner P, Higgins T, Potter F, Warren M (2009) Global Biofuels Outlook 2009-2015: Projecting Market Demand by Country, Region and Globally. http://www.globalbiofuelscenter.com/

Knight F H (1921) Risk, Uncertainty and Profit, Houghton Mifflin, Boston, USA

Koh L P (2007) Impending disaster or sliver of hope for Southeast Asian forests? The devil may lie in the details. *Biodiversity Conservation* 16, 3935–3938.

Koh L P, Ghazoul J (2008) Biofuels, biodiversity, and people: understanding the conflicts and finding opportunities. *Biological Conservation* 141, 2450–2460.

Kotto-Same J, Moukam A, Njomgang R, Tiki-Manga T, Tonye J, Diaw C, Gockowski J, Hauser S, Weise S, Nwaga D, Zapfack L, Palm C, Woomer P, Gillison A, Bignell D, Tondoh J (2000) Alternatives to Slash-and-Burn Summary Report and Synthesis of Phase II in Cameroon. Nairobi, ICRAF. 72 pp http://www.worldagroforestry.org/downloads/publications/PDFs/B14791.pdf

Lapola D M, Schaldach R, Alcamo J, Bondeau A, Koch J, Koelking C, Priess J A, (2010) Indirect land-use changes can overcome carbon savings from biofuels in Brazil. Published online before print on February 8, 2010, doi: 10.1073/pnas.0907318107.

Lathwell D J (1990) Legume green manures. Principles for management based on recent research. *TropSoils Bulletin* 90-01. Soil Management Collaborative Research Support Program, North Carolina State University, Raleigh, USA.

Lobell D B, Field C B (2007) Global scale climate–crop yield relationships and the impacts of recent warming. *Environmental Research Letters* 2, 014002.

Lohmann L (2006) Carbon Trading, a critical conversation on climate change, privatisation and power. *Development Dialogue* 48, 362 pp. http://www.dhf.uu.se/pdffiler/DD2006_48_carbon_trading/carbon_trading_web.pdf

Maley J, Brenac P (1998) Vegetation dynamics, palaeoenvironments and climatic changes in the forests of western Cameroon during the last 28000 years BP. *Review of Palaeobotany and Palynology* 99, 157-187.

Manson S, Evans T (2007) Agent-based modeling of deforestation in southern Yucatan, Mexico, and reforestation in the Midwest United States. *Proceedings of the National Academy of Sciences* 104, 20678-20683.

Mathews J A, Tan H (2009) Biofuels and indirect LUC effects: the debate continues. *Biofuels, Bioproducts & Biorefining* 3, 305-317.

Melillo J M, Reilly J M, Kicklighter D K, Gurgel A C, Cronin T W, Paltsev S, Felzer B S, Wang X, Sokolov A P, Schlosser C A (2009) Indirect emissions from biofuels: how important? *Science* 326, 1397 – 1399.

Menichetti E, Otto M (2009) Energy Balance & Greenhouse Gas Emissions of Biofuels from a Life-Cycle Perspective. Biofuels: Environmental Consequences and Interactions with Changing Land Use. In: Howarth RW, Bringezu S, eds., Proceedings of the Scientific Committee on Problems of the Environment (SCOPE) International Biofuels Project Rapid Assessment, 22-25 September 2008, Gummersbach, Germany, 81-109.

Mertens B, Lambin E F (2000) Land cover change trajectories in southern Cameroon. *Annals of the Association of American Geographers* 90, 467-494.

Midmore D J (1993) Agronomic modification of resource use and intercrop productivity. *Field Crops Research* 34, 357-380.

Moad A S, Whitmore J L (1994) Tropical forest management in the Asia-Pacific region. *Journal of Sustainable Forestry* 1, 25-63.

National Research Council (2007) Water Implications of Biofuels Production in the United States. Committee on Water Implications of Biofuels Production in the United States, ISBN: 0-309-11360-1, 86 pp. http://www.nap.edu/catalog.php?record_id=12039

Nelson G C, Rosegrant M W, Koo J, Robertson R, Sulser T, Zhu T, Ringler C, Msangi S, Palazzo A, Batka M, Magalhaes M, Valmonte-Santos R, Ewing M, Lee D (2009) Climate Change Impact on Agriculture and Costs of Adaptation. International Food Policy Research Institute, Washington, D.C. 30 pp. http://www.ifpri.org/publication/climate-change-impact-agriculture-and-costs-adaptation

Norgrove L (2006) Conflicting views of changes in forest cover in the forest savannah transition zone in central Cameroon. *International Workshop for Afrikanists in Germany*. Centre for Interdisciplinary Africa Research, Frankfurt am Main, Germany.

Norgrove L (2010) Impacts of biofuel production on food security. IUFoST Scientific Information Bulletin, March 2010. 21 pp http://iufost.org/sites/default/files/docs/IUF.SIB.BiofuelProduction.pdf

Oerke E C, Dehne H W (1997) Global crop production and the efficacy of crop protection – current situation and future trends. *European Journal of Plant Pathology* 103, 203–215.

Ou Xunmin, Zhang Xiliang, Chang Shiyan, Guo Qingfang (2009) Energy consumption and GHG emissions of six biofuel pathways by LCA in (the) People's Republic of China. *Applied Energy* 86, S197–S208.

Pfister S, Hellweg S, (2009) The water ''shoesize'' vs. footprint of bioenergy. *Proceedings of the National Academy of Sciences* 106, E93–E94.

Pimentel D, Patzek T W (2005) Ethanol production using corn, switchgrass, and wood; biodiesel production using soybean and sunflower. *Natural Resources Research* 14, 65-76.

Pontius R G, Neeti N (2010) Uncertainty in the difference between maps of future land change scenarios. *Sustainability Science* 5, 39-50.

Pontius R G, Walker R, Yao-Kumah R, Arima E, Aldrich S, Caldas, M, Vergara D (2007) Accuracy assessment for a simulation model of Amazonian deforestation. *Annals of the Association of American Geographers* 97, 677-695.

Ramankutty N, Foley J A (1999) Estimating historical changes in global land cover; croplands from 1700 to 1992. *Global Biogeochemical Cycles* 13, 997–1028.

Rathmann R, Szklo A, Schaeffer R (2010) Land use competition for production of food and liquid biofuels: an analysis of the arguments in the current debate. Renewable Energy 35, 14–22.

Renewable Fuels Agency (2008) The Gallagher Review of the Indirect Effects of Biofuels Production available at http://www.renewablefuelsagency.gov.uk/reportsandpublications/reviewoftheindirecteffectsofbiofuels.

Righelato R, Spracklen D V (2007) Carbon mitigation by biofuels or by saving and restoring forests? *Science* 317, 902.

Rindfuss R R, Walsh S J, Turner II B L Fox J, Mishra V (2004) Developing a science of land change: challenges and methodological issues. *Proceedings of the National Academy of Sciences* 101, 13976-13981.

Robiglio V, Mala W A, Diaw M C (2003) Mapping landscapes: integrating GIS and social science methods to model human-nature relationships in Southern Cameroon. *Small-scale Forest Economics, Management and Policy* 2, 171-184.

Robiglio V, Sinclair F (2007) One Step Back; One Step Forth. Agricultural Expansion and Landscape Change Trajectories in Shifting Cultivation System in Southern Cameroon. Proceedings of International Association of Landscape Ecology World Congress 8-12 July 2007, Wageningen, the Netherlands. http://www.landscape-ecology.org

Sanderson K (2009) Wonder weed fails to flourish. *Nature* 461, 328-329.

Schimel D S, House J I, Hibbard K A (2001) Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. *Nature* 414, 169–172.

Schlenker W, Roberts M J (2009) Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proceedings of the National Academy of Sciences* 106, 15594-15598.

Searchinger T (2008) http://www.sciencemag.org/cgi/eletters/319/5867/1238#10977

Searchinger T, Heimlich R, Houghton R A , Dong F, Elobeid A, Fabiosa J, Tokgoz S, Hayes D, Yu T H (2008) Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science* 319(5867), 1238-40.

Sitch S, Smith B, Prentice I C (2003) Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model. *Global Change Biology* 9, 161–185.

Smeets E M W, Faaij A P C, Lewandowski I M, Turkenburg W C (2007) A bottom-up assessment and review of global bio-energy potentials to 2050. ***Progress in Energy and Combustion Science*** 33, 56 – 106.

Solomon B D (2010). Biofuels and sustainability. ***Annals of the New York Academy of Sciences*** 1185, 119–134.

Solomon D, Fritzsche F, Lehmann J, Tekalign M, Zech W (2002) Soil organic matter dynamics in the sub-humid agro-ecosystems of the Ethiopian Highlands: Evidence from natural 13C abundance and particle size fractionation. ***Soil Science Society of America Journal*** 66, 969–978.

State of California, Office of the Governor (2007) Executive Order S-1-07 http://gov.ca.gov/executive-order/5172/.

State of California, Air Resources Board, *California Global Warming Solutions Act (AB32),* 27 September 2006, http://www.arb.ca.gov/cc/cc.htm.

Sunderlin W D, Rodríguez J A (1996) Cattle, broadleaf forests and the agricultural modernization law of Honduras: the case of Olancho. CIFOR Occasional Paper 7, 28 pp. http://www.cifor.cgiar.org/templates/PubPredefined.aspx?NRMODE=Published&NRORIGINALURL=%2fPublications%2fPapers%2f&NRNODEGUID={F534A976-8AC9-4577-B158-734E91ADF063}&NRCACHEHINT=NoModifyGuest

Tchienkoua M, Zech W (2004) Organic carbon and plant nutrient dynamics under three land uses in the highlands of West Cameroon. *Agriculture, Ecosystems and Environment* 104, 673–679.

Thenkabail P S (1999) Characterization of the alternative to slash-and-burn benchmark research area representing the Congolese rainforests of Africa using near-real-time SPOT HRV data. *International Journal of Remote Sensing* 20, 839-877.

Tiessen H, Stewart J (1983) Particle size fractions and their use in studies of soil organic matter 2. Cultivation effects on organic matter composition in size fractions. *Soil Science Society of America Journal* 47, 509–514.

Tiffen M, Mortimore M (1994) Malthus controverted – the role of capital and technology in growth and environment recovery in Kenya. *World Development* 22, 997–1010.

Tilman D, Hill J, Lehman C (2006) Carbon-negative biofuels from low-input high-diversity grassland biomass. *Science* 314, 1598-1600.

Trostle R (2008) Global agricultural supply and demand: Factors contributing to the recent increase in food commodity prices. Outlook Report No. WRS-0801, Economic Research Service, U.S. Department of Agriculture, Washington, DC, May. http://www.ers.usda.gov/Publications/WRS0801/

Tuck G, Glendining M J, Smith P, House J I, Wattenbach M (2006) The potential distribution of bioenergy crops in Europe under present and future climate. *Biomass and Bioenergy* 30, 183–197.

United Nations Environment Programme (2009) Assessing Biofuels http://www.unep.fr/scp/rpanel/pdf/Assessing_Biofuels_Full_Report.pdf

United Kingdom, Office of Public Sector Information (2007) Renewable Transport Fuel Obligation Order 2007, No. 3072,25 http://www.opsi.gov.uk/si/si2007/pdf/uksi_20073072_en.pdf

U.S. Environmental Protection Agency (2010) 40 CFR Part 80 – Regulation of fuels and fuel additives: Changes to Renewable Fuel Standard Program http://edocket.access.gpo.gov/2010/pdf/2010-3851.pdf

U.S. Government Printing Office, Superintendent of Documents (2007) *Energy Independence and Security Act of 2007 (P.L. 110-140)* http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf

Vanclay J K (2003) Why model landscapes at the level of households and fields?, ***Small-scale Forest Economics**, **Management and Policy*** 2, 121-134.

Verburg P H, Soepboer S, Veldkamp T A, Limpiada R, Espaldon V, Sharifah Mastura S A (2002) Modeling the spatial dynamics of regional land use: the CLUE-S Model. *Environmental Management* 30, 391-405.

Vincens A, Dubois M A, Guillet B, Achoundong G, Buchet G, Kamgang Kabeyene Bayala V, de Namur C, Riera B (2000) Pollen-rain-vegetation relationships along a forest-savanna transect in Southeastern Cameroon. *Review of Paleobotany and Palynology* 110, 191–208.

Voet E van der; Lifset R J; Luo L (2010) Life-cycle assessment of biofuels, convergence and divergence. Biofuels 1, 435–449. http://www.future-science.com/doi/abs/10.4155/bfs.10.19

Waller J M, Bigger M, Hillocks R J (2007) Coffee pests, diseases and their management. CABI, Wallingford, UK, 434 pp. http://bookshop.cabi.org/

Walkley A, Black L A (1934) An examination of Degtjareff method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Science* 37, 29–38. http://journals.lww.com/soilsci/Citation/1934/01000/An_Examination_of_the_Degtjareff_Method_for.3.aspx

Wilson A T (1978) Pioneer agriculture explosion and CO2 levels in the atmosphere. *Nature* 273, 40–1.

Woods J (2009) Bioenergy and indirect LUC. IPIECA Workshop on Indirect LUC (ILUC) 9th Nov 2009 Hotel Royal Savoy, Lausanne, Switzerland.

Yan X, Inderwildi O R, King D A (2010) Biofuels and synthetic fuels in the US and China: a review of Well-to Wheel energy use and greenhouse gas emissions with the impact of land-use change. *Energy & Environmental Science* 3, 190-197.

Young A (1999) Is there really spare land? A critique of estimates of available cultivable land in developing countries. Environment, Development & Sustainability 1, 3–18.

Zech W, Guggenberger G, Schulten H R (1994) Budgets and chemistry of dissolved organic carbon in forest soils: effects of anthropogenic soil acidification. *Science of the Total Environment* 152, 49–62.

Ziska L H, Runion G B, Tomecek M, Prior S A, Torbet H A, Sicher R (2009) An evaluation of cassava, sweet potato and field corn as potential carbohydrate sources for bioethanol production in Alabama and Maryland. ***Biomass and Bioenergy*** 33, 1503-1508.

.