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UNU-IAS Policy Report

Impacts of Liquid Biofuels on Ecosystem Services and Biodiversity

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Impacts of Liquid Biofuels on Ecosystem Services and Biodiversity

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Foreword

The world is on the brink of a confounding crisis, which is brought about by a cumulating cascade of factors such as rapid changes in our natural climatic conditions, environmental degradation brought about by unsustainable production and consumption practices, depletion of environmental and biological resources, and a sharp decline in various indicators of well-being. While noting that it is our actions and, often times, inactions that have precipitated these impending crises, it is imperative that we the citizens of our planet should quickly come up with effective measures to mitigate the consequences and adapt to the changes in our natural ecosystems. This would require us to pay more attention to the enhancement and maintenance of natural resources and processes as well-functioning ecosystems with the diversity of resources contained therein so as to enable sustainable production, consumption, and related livelihood activities. Obviously, this would require inputs from various scientific, technological, and allied academic fields in terms of innovations and radically new ideas; from business communities by fostering best practices in the use and disposal of resources and transactions with others in the supply chain; from civil society in fostering responsible stewardship of natural resources and social concerns; and, from governments in terms of development and implementation of appropriate policies that are sensitive to the needs of the diverse sections of the society they govern. And the implications of actions by the various stakeholders need to be analysed in a timely, and, often, anticipatory manner, in order to draw attention to benefits and concerns related to decisions made at different levels.

In this context, I am pleased to state that the United Nations University Institute of Advanced Studies (UNU-IAS) has been actively contributing to advancing awareness of various concerns related to biodiversity and ecosystems among a variety of stakeholders. Our research has straddled areas in the interface between the natural world, human aspirations, and well-being consequences. We have focused especially on the notion of fostering equitable transactions between different stakeholders over the years.

This year, we are launching several new publications that are of particular relevance to the Conference of Parties (COP) to the Convention on Biological Diversity (CBD). The publications examine a diverse set of topics that include, among others, the effectiveness of implementation of national biodiversity strategies by different countries; the governance and management of bio-cultural landscapes such as satoyama and satoumi; the status of biodiversity in the South East Asian region; the impact of emerging biofuel technologies to the provision of ecosystems services; scoping the role of urban centres in green development; and underscoring the need for bridging epistemological divides between modern and traditional world views in securing development goals and conservation priorities – all of which are topics that are of keen import to the CBD's objectives as well as to the broader sustainable development agenda. I expect each of these publications will provide a basis to inform discussions and facilitate designing of implementable policies in their related areas.

I would like to take this opportunity to thank our partners and collaborators for their support in our research and capacity development activities. There are several expectations from the outcomes of this COP, and we hope to continue our work in the future informing and providing relevant inputs to policy-makers, academics, and practitioners alike.

Govindan Parayil
Director, UNU-IAS
September 2010

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Executive Summary

Ecosystem services are the benefits people obtain from ecosystems. Biofuels can provide a number of ecosystem services (e.g. fuel, climate regulation) but also compromise other ecosystem services (e.g. food, freshwater services) and biodiversity which are of paramount value for human well-being. However, knowledge about the effect of biofuels on ecosystem services and biodiversity is fragmented and in some cases is still only emerging. Moreover, the effect depends on several interconnected factors.

This report collects and critically discusses the existing literature regarding the drivers, impacts, and trade-offs involved in biofuel production. In particular, the ecosystem services concept can be used to rationalise and put into perspective the existing evidence about biofuels' impact on ecosystems as it has been identified by diverse academic disciplines.

By employing the classification of ecosystem services popularised by the Millennium Ecosystem Assessment (MA), it is shown how biofuel production both provides and compromises ecosystem services over its life cycle. At the same time, it is shown that biofuels can negatively affect biodiversity. In fact, biofuel expansion in certain areas of the world, such as Indonesia and Brazil, is being considered as one of the main emerging threats to biodiversity.

With these findings in mind, this report concludes by discussing certain response options that can be further developed to enhance the long-term sustainability of biofuels by minimising their impact on ecosystem services and biodiversity. The key responses discussed include the use of degraded land for the production of biofuel feedstock, the adoption of improved management practices, the development of designer landscapes, and the adoption of innovative schemes such as Payment for Ecosystem Services (PES), Reduction of Emissions from Deforestation and Degradation (REDD), and biofuel certification.

1. Introduction

Energy demand is set to increase significantly in the coming decades, especially as a consequence of rapid economic development in the developing world (IEA, 2009). Scarcity of readily available fossil fuels, their uneven geographical distribution as well as geopolitical factors can severely affect national economies and international markets. Meanwhile, fossil fuel combustion is the single most important driver of human-induced climate change (IPCC, 2007). Consequently, energy security, economic development, and environmental protection have become three recurrent and closely intertwined themes in policy discussions globally. Due to such concerns, the development of copious amounts of cheap, renewable, evenly distributed, and environmentally friendly energy has become a central element of several national energy strategies.

Possibly the most controversial of such energy sources is first generation biofuels used as liquid fuel for transportation, which is the focus of this report (e.g. biodiesel and bioethanol derived from the seed, grain or whole plant of crops usually used for food such as corn, sugar cane, and oil palm)[1]. Certain biofuel practices can be net energy suppliers (Hill, et al., 2006; Menichetti and Otto, 2009), environmentally friendly (Zah, et al., 2008), and socioeconomically beneficial (Arndt, et al., 2010; FAO, 2009). On the other hand, interestingly, there is also significant evidence that biofuels not only provide a number of ecosystem services[2] but that they also compromise other ecosystem services such as food (Fischer, et al., 2009) and freshwater services (SCOPE, 2009), and affect negatively the climate (Fargione, et al., 2008), biodiversity (Fitzherbert, et al., 2008), and food prices (Fischer, et al., 2009; Mitchell, 2008). Furthermore, biofuel production can sometimes deprive livelihood options for the poorer strata of society (Cotula, et al., 2008). However, this knowledge is fragmented and data is still rudimentary largely due to the fact that most existing biofuel programs are still only in their infancy.

Liquid biofuel production has increased by a factor of 5 since the early 1990s (refer to Figure 1). First generation biofuel production will expand significantly in developing nations in the short to medium term (OECD-FAO, 2010), including South East Asia (Ölz and Beerepoot, 2010). It has been suggested that biofuels need to be net energy providers, environmentally sustainable, economically competitive, not compete with food production and be socially beneficial if they are to make a positive contribution to society and the environment (Hill, et al. 2006, Rist, et al., 2009). However, whether biofuel production can have a negative or positive impact on the environment and human well-being depends on a multitude of factors ranging from the production technologies and processes adopted, to the characteristics of the surrounding ecosystems, and the policies that govern biofuel production and trade. Consequently, it is far from trivial to assess the net social and environmental costs and benefits associated with biofuel production.

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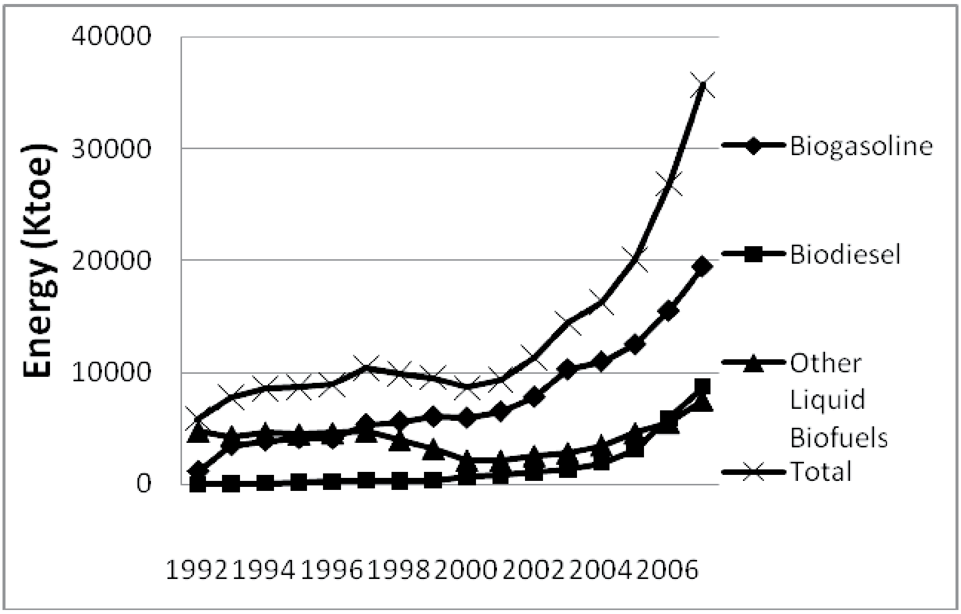
[1] Second generation biofuels can be produced from plant material rich in lignocellulose such as wheat straw, corn stover, Miscanthus, switchgrass and woodchips among others.

[2] Ecosystem services are broadly defined as the "…benefits people obtain from ecosystems" (MA, 2005: 27)

Figure 1: Production of Liquid Biofuels Globally, 1992-2007



Source: IEA, 2010.

Given this context, the aim of this report is to provide an overview of the current literature with respect to the impact that biofuel production has on ecosystem services and biodiversity. In particular, this report seeks to provide:

- A consistent review of the impacts of first generation biofuels on ecosystem services and biodiversity
- An overview of the options available for mitigating the impact of biofuel production on ecosystem services and biodiversity

It should be noted that there is an abundant literature on the impacts of biofuels,[3] spanning several academic disciplines and spatial scales. Additionally, there are several biofuel production practices which can have radically different impacts across different spatial scales. Consequently, this report does not attempt to provide an exhaustive review of the literature but rather highlights the main impacts of biofuel on ecosystem services and biodiversity, which have important consequences for human well-being at the local, regional, and global scale.

Section 2 introduces the Millennium Ecosystem Assessment (MA) framework as applied to biofuel production. Section 3 provides an overview of the direct and indirect drivers to ecosystem change and biodiversity loss as related to biofuels. Section 4 reviews the literature on the impacts of biofuels on ecosystems services, while section 5 reviews the impacts on biodiversity. In section 6, different response options which can be deployed to enhance the sustainability of biofuels are recommended, followed by concluding remarks in the last section.

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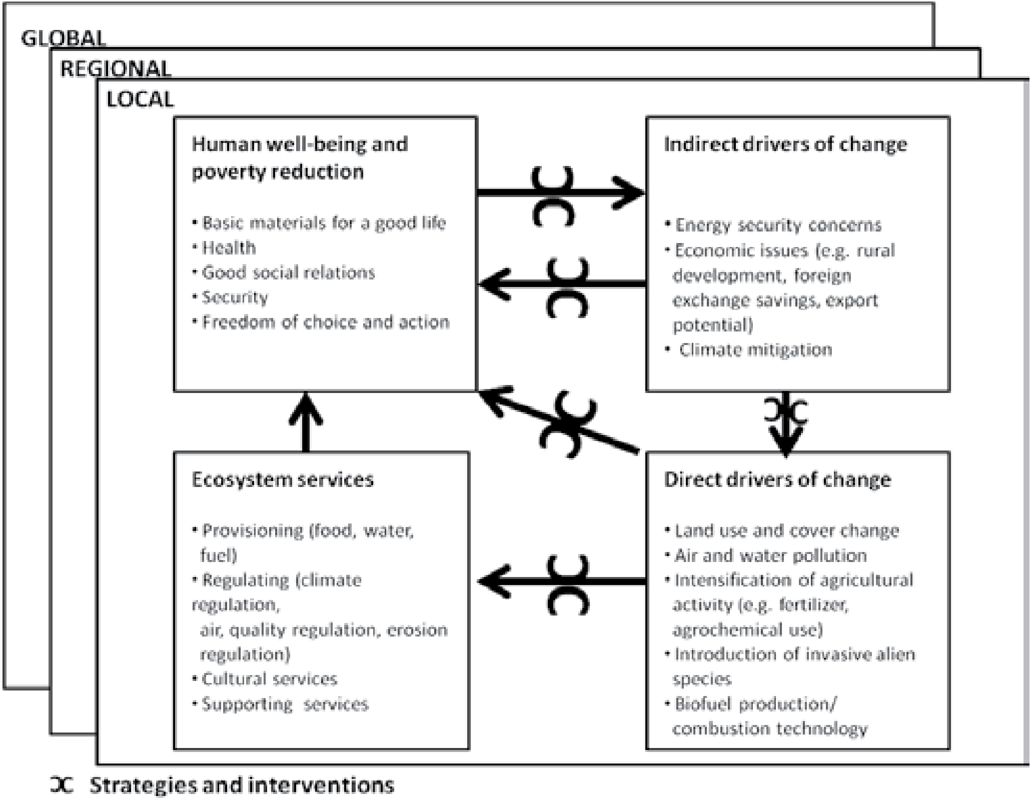
[3] Currently, most of the published material is relevant to corn bioethanol in the US, sugar cane bioethanol in Brazil, and oil palm biodiesel in Indonesia/Malaysia. This literature forms the backbone of this review but significant evidence from other areas/feedstocks is increasingly being published and collected in this review.

2. The MA Framework as Applied to Biofuels

Using the ecosystem services approach when discussing the trade-offs involved in biofuel production offers several advantages. First of all, the ecosystem services concept explicitly bridges ecosystem impact and human well-being, which are two key components of the biofuel debate brought forward by proponents and critics of biofuels alike. Hence, this conceptual framework can help to highlight the many values of natural capital, as well as the social costs and benefits associated with biofuel expansion. Moreover, the ecosystem services concept has gained popularity in the academic community (Fisher, et al., 2009), and most importantly, has gained understanding and high-level acceptance among policy-makers. For example, the concept has been adopted by the United Nations Convention of Biological Diversity (CBD)[4], a multilateral environmental agreement. Hence the MA framework is in a unique position to become a standardised analytical framework for sustainability analysis of biofuels, agreeable and understood by multiple stakeholders (Stromberg, et al. 2009). It is the authors' hope that this will be helpful to further the knowledge and response options across stakeholders with vastly different incentives and approaches toward biofuels.

Figure 2: MA Conceptual Framework related to Biofuel Production (adapted from MA, 2005)



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[4] It is interesting to note that biofuels are also high in CBD's agenda (e.g. refer to CBD COP 9 decision Number 2 at <http://www.cbd.int/decisions/cop/?m=cop-09>), or the agenda for CBD COP 10, at <http://www.cbd.int/doc/meetings/cop/cop-10/official/cop-10-01-en.pdf>.

Figure 2 is an adaptation of the MA conceptual framework and illustrates how this report will approach the review of the academic literature. Sections 3-5 describe how industrialised and developing countries (e.g. Europe, US, Philippines and Indonesia) have engaged in biofuel expansion as a way to meet their various policy targets such as securing a reliable supply of transport fuel and what the impacts on ecosystem services and biodiversity have been. For example, apart from generating fuel, a provisioning service, biofuel production can have negative effects on other ecosystem services such as food due to the rise in demand of food crops for bioethanol/biodiesel production. Such effects on ecosystem services can in turn affect positively or negatively on human well-being and poverty reduction (top left square).

Figure 3: Interlinkages of Biofuel Production, Ecosystem Services, and Human Well-being (adapted from MA, 2005)

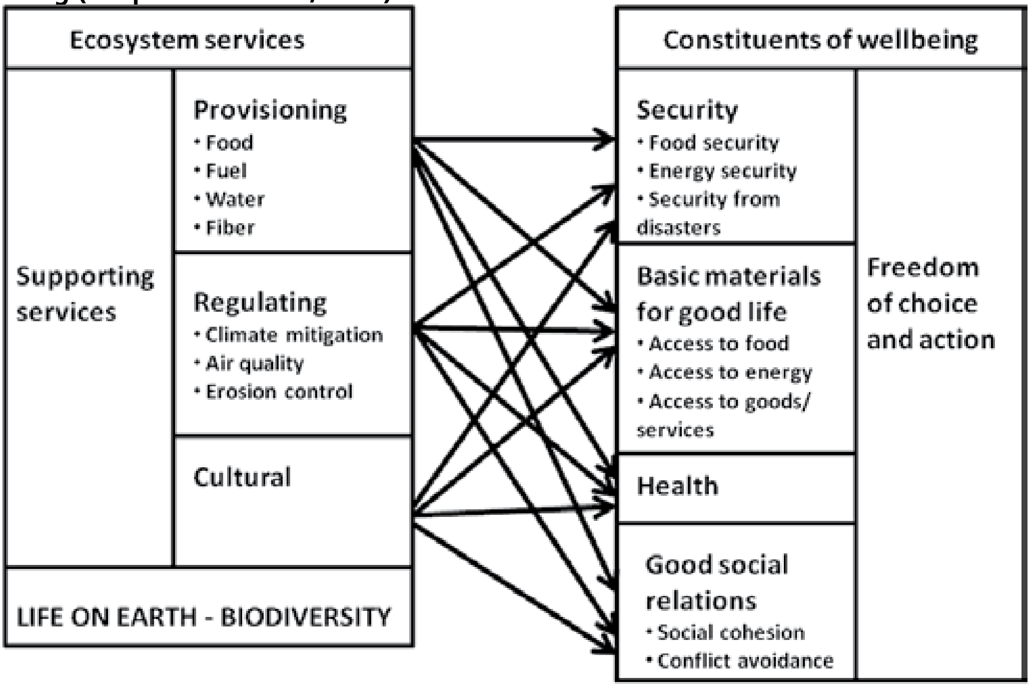

Figure 3 depicts in a tentative way the linkages between ecosystem services and human well-being in the context of biofuel production. For example, biofuel expansion may increase access to fuel but also reduce access to food, hence affecting both security and basic materials supporting livelihoods. Lastly, strategies and interventions such as land use planning can enhance the ecosystem and social benefits resulting from the linkages among the four squares of Figure 1. Examples of such response measures are given in section 6.

3. Drivers to Ecosystem and Biodiversity Loss related to Biofuels

Commonly cited policy drivers for large-scale biofuel production are energy security, climate change mitigation, foreign exchange savings, and rural development, which represent very different underlying policy motivations and incentives (Yan and Lin, 2009). Energy security has often been the overarching driver (e.g. in China, India, Brazil, USA, EU), while in other cases, trade balance and rural development have played much more significant roles, e.g. sub-Saharan nations (Jumbe, et al., 2009; Bekunda, et al., 2009). Climate change mitigation has been a significant driving force in some developed nations (e.g. EU) but have only marginally, if at all, influenced developing nations to switch towards greater biofuel production (e.g. Zhou and Thomson, 2009)[5].

Biofuel production[6] and use can impact ecosystems during each stage of their life cycle[7]. The different processes adopted at each of these stages can impact ecosystem services/ human well-being in differing degrees and can make the difference on whether biofuel production/use can be sustainable in the long-term. The key indirect and direct drivers of biofuels' production impact on ecosystem change are collected in Table 1.

Table 1: Key Direct and Indirect Drivers of Biofuels' Production Impact on Ecosystem Change and Biodiversity

Indirect Drivers	Direct Drivers
Energy security concerns (mainly at the regional and local level)	Land use and cover change (LUCC)
	Air and water pollution
Economic concerns (mainly at the regional and local level) -Rural development -Savings in foreign exchange -Export potential	Intensification of agricultural activity (e.g. fertilisers and agrochemical use) Introduction of invasive alien species
Climate mitigation (mainly at the global level)	Biofuel production/combustion technology

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[5] One of the potential reasons is the fact that developing nations have been included in Annex A of the United Nations Framework Convention on Climate Change (UNFCCC) and as a result they are not currently bound to reduce their GHG emissions by the Kyoto Protocol.

[6] First generation biofuel feedstock production is essentially an agricultural activity which is in most cases based on monocultures.

[7] The main stages of the biofuel life cycle include feedstock production, feedstock transport, biofuel production, biofuel distribution/storage/dispensing, and biofuel combustion (Hess, et al., 2009; Delucchi, 2006).

4. Impacts of Biofuel Production on Ecosystem Services

This section presents how biofuel production can affect provisioning, regulating, and cultural services[8]. The evidence presented encompasses the impacts of several feedstocks (e.g. corn, sugar cane, oil palm, and jatropha) in several areas around the world.

4.1 Provisioning Services

4.1.1 Fuel

Liquid biofuels are currently mainly used as additives in conventional transport fuels, but in some cases, they are substituting conventional transport fuel altogether (IEA, 2004)[9]. The two most common forms of liquid biofuels are bioethanol and biodiesel[10]. Brazil has been a leader in the introduction of biofuels (sugar cane ethanol) in the transport sector since the mid-1970s and its pro-Alcool programme. For several reasons, the Brazilian experiment is deemed as an economic/energy security success[11] (e.g. Abramovay, 2008; Fischer, et al., 2009), and other countries are trying to copy Brazil's success. Currently, a number of countries across the world have mandated different proportions of biofuels to be mixed in as transport fuel (Table 2).

Table 2: Biofuel Mandates for Different Countries

Country	Mandate
EU	5.75% of transport fuel by 2010, 10% by 2020
USA	7.5 billion gallons by 2012, 36 billion by 2022
Brazil	20-25% anhydrous ethanol for gasoline; 3% biodiesel for diesel fuel 2008 rising to 5% by the end of 2010
China	15% of transport fuel by 2020
India	Proposed blending mandates of 5-10 per cent of ethanol and 20 per cent of biodiesel
Canada	5% of gasoline by 2010; 2% biodiesel for diesel fuel and heating oil by 2012

Source: Rudaheranwa, 2009.

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[8] This report does not address the effect of biofuels on supporting services as the academic literature has yet to address this topic sufficiently.

[9] Biofuels can also be used and for other purposes such as rural electrification (FAO, 2009a)

[10] In some cases, pure vegetable oil can be used as a fuel for transport, cooking, and power generation. Given that vegetable oil is the raw material for biodiesel production, the literature regarding the impacts of vegetable oil production as a fuel is discussed alongside the literature for biodiesel.

[11] It goes without saying that sugar cane ethanol production in Brazil has also significant negative impacts.

Bioethanol can be obtained from the fermentation of sugar or starch rich crops such as corn, sugar cane, cassava, sugar beet, wheat, and molasses (Fischer, et al., 2009). Bioethanol is by far the most widely produced biofuel globally, with most of it being produced in the US (from corn), Brazil (from sugar cane), China (from corn) and India (from molasses) (IEA, 2010).

Biodiesel is produced through the transesterification of animal and vegetable fats (Fischer, et al., 2009) most commonly derived from rapeseed, soybeans, sunflower seed, palm oil, and jatropha. Numerous other oilseeds are currently used or assessed as biodiesel feedstock. Currently, the biggest producer and consumer of biodiesel is the EU (mainly from rapeseed) while emerging players are Brazil (from soybeans) and Malaysia/Indonesia (from palm oil). There is also considerable attention to produce biodiesel from jatropha in India, China, and several Sub-Saharan nations. Jatropha's ability to be cultivated in marginal lands using little amounts of water has the potential to ease the direct competition with food production (e.g. Achten, et al., 2008; Sano, et al., forthcoming).

As mentioned in the introduction, a key consideration regarding the viability of biofuels is whether they provide net energy gains, as compared with conventional fossil fuels (Hill, et al., 2006). The amount of non-renewable energy used during the whole life cycle of the biofuel is considered a key indicator of the biofuel's viability, and Life Cycle Analysis[12] (LCA) has been identified as the most adequate tool to assess such issues (e.g. Menichetti and Otto, 2009; Hill, et al., 2006; Zah, et al., 2007).

One LCA meta-analysis, conducted by Menichetti and Otto (2009), found that most first generation biofuel production practices are net energy providers albeit to differing degrees, refer to Tables 3-4. Another meta-analysis conducted by de Vries, et al. (2010) found that biofuel production from sugar cane (bioethanol), sweet sorghum (bioethanol), and oil palm (biodiesel) provided significant energy gain compared to standard transport fuels. Biofuel from sugar beet (bioethanol), cassava (bioethanol), rapeseed (biodiesel), and soybean (biodiesel) had the next highest energy gains, but biofuel from corn (bioethanol) and wheat (bioethanol) showed the least energy gain (ibid). Finally, a comparative LCA study has ranked different biodiesel production chains according to their use of non-renewable energy (Panichelli, et al., 2009). The order in decreasing energy consumption is soybean (Argentina), soybean (Brazil), rapeseed (EU), rapeseed (Switzerland), palm oil (Malaysia), and soybeans (USA).

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[12] LCA results are sensitive to the allocation methods used among several other unresolved methodological issues.

Table 3: Fossil Energy and GHG Improvement for Bioethanol Production

Feedstock	Country	Fossil Energy Improvement	GHG Improvement	Reference
Corn	USA	34%; 16%	13% ; -2%	(Farrell, et al., 2006)
Corn	USA	68%	20% (-47% ; +58%)	(Grood and Heywood, 2007)
Corn	USA	33-64%	-5% ; 30%	(Unnasch and Pont, 2007)
Corn	USA	36% (30-70%)	19% (-3% ; +52%)	(Wang, et al., 2007)
Corn	USA	26%	-4%	(De Oliveira, et al., 2005)
Corn	USA	39%	35%	(Shapouri, et al., 2002)
Corn	USA, China	37%	18%	(Zah, et al., 2007)
Wheat	Various	16-85%	18-90%	(Quirin, et al., 2004)
Wheat	Various	61%	64%	(Elsayed, et al., 2003)
Wheat	Europe	42% (22-115%)	32%	(Edwards, et al., 2007)
Wheat	Canada	61%	48%	(S&T Consultants, 2006)
Wheat	Spain	42%	78%	(Lechon, et al., 2005)
Wheat	France	57%	60%	(Ecobilan, 2002)
Sugar cane	Brazil,Africa	90%	>100%	(DeCastro, 2007)
Sugar cane	Brazil	>90%	85-90%	(Smeets, et al., 2006)
Sugar cane	Europe	>90-100%+	-87%	(Edwards, et al., 2007)
Sugar cane	USA	86%	84%	(Unnasch and Pont, 2007)
Sugar cane	Brazil, USA	78%	>70%	(De Oliveira, et al., 2005)
Sugar cane	Brazil	91%	86%	(Macedo, et al., 2004)
Sugar cane	Brazil, China	89%	85%	(Zah, et al., 2007)
Sugarbeet	Europe	48% (24-73%)	48% (32-65%)	(Edwards, et al., 2007)
Sugarbeet	France	58%	61%	(Ecobilan, 2002)
Sugarbeet	Various	58%	51%	(Elsayed, et al., 2003)
Sugarbeet	China	73%	65%	(Zah, et al., 2007)
Sugarbeet	Switzerland	85%	40%	(Gnansounou and Dauriat, 2004)

Source: (Menichetti and Otto, 2009)

Table 4: Fossil Energy and GHG Improvement for Biodiesel Production

Feedstock	Country	Fossil Energy Improvement	GHG Improvement	Reference
Rapeseed	Various	65%	53%	(Elsayed, et al., 2003)
Rapeseed	Belgium, Germany	55%	45%	(Puppan, 2001)
Rapeseed	Europe, Brazil	56-61%	41-47%	(Edwards, et al., 2007)
Rapeseed	Spain	79%	56%	(Lechon, et al., 2005)
Rapeseed	France	80%	80%	(Ecobilan, 2002)
Rapeseed	Europe	43%	55% (30-85%)	(Choudhury, et al., 2002)
Rapeseed	Various	46-54%	64%	(Zah, et al., 2007)
Soybean	Brazil, Africa	NA	53-78%	(DeCastro, 2007)
Soybean	Europe, N. America	-70%	45-75%	(Larson, 2005)
Soybean	Various	>100%	68-110%	(Quirin, et al., 2004)
Soybean	Europe, Brazil	67%l	67%	(Edwards, et al., 2007)
Soybean	Brazil	27%	-17%	(Zah, et al., 2007)
Soybean	USA	40%	40%	(Zah, et al., 2007)
Sunflower seed	Various	72-139%	35-110%	(Quirin, et al., 2004)
Sunflower seed	Europe, Brazil	67%	67%	(Edwards, et al., 2007)
Sunflower seed	Spain	76%	66%	(Lechon, et al., 2005)
Sunflower seed	France	83%	83%	(Ecobilan, 2002)
Palm oil	Thailsnd, Spain	64%	40%	(Lechin, et al., 2006)
Palm oil	Malaysia, China	64%	70%	(Zah, et al., 2007)
Palm oil	Indonesia, Malaysia	NA	80%	(Beer, et al., 2007)
Canola	South Africa	NA	25%	(Stephenson, et al., 2010)
Soybean	South Africa	NA	22%	(Stephenson, et al., 2010)
Sunflower seed	South Africa	NA	20-21%	(Stephenson, et al., 2010)
Sunflower seed	South Africa	NA	34-36%	(Stephenson, et al., 2010)
Jatropha	West Africa	NA	72%	(Ndong, et al., 2009)

Source: (Menichetti and Otto, 2009)

Straight jatropha oil can be used directly as a fuel without prior processing. LCAs on the production and use of straight jatropha oil as a biofuel have shown significant net energy gains when compared with conventional fuels (e.g. Gmunder, et al., 2010). However, it is generally accepted that it is not as energy efficient when compared to jatropha biodiesel, and it can cause malfunction in the combustion engine. For jatropha biodiesel, LCA has shown that this production chain is generally a net energy provider with the biodiesel production stage (transesterification) being the most energy demanding stage (Achten, et al., 2008; Reinhardt, et al., 2007).

These findings suggest that first generation biofuels can be a feasible energy option in the short-to-medium term, and as such contribute positively to energy security. Brazil is a prime example with large-scale biofuel production contributing a significant fraction of all the transport fuel consumed in the country. In 2008, almost 21% of the transport fuel consumed in the transport sector came from biofuels and was equivalent to 12 million tons of oil equivalent (IEA, 2010). Biofuels have penetrated the transport sector and in European countries, but to a lesser degree than Brazil (refer to Table 5).

Table 5: Biofuel Penetration in Selected European Countries

(biofuel over energy content in fuels, 2009). **Country**	**Biofuel Use in Transport**
Germany	7.88 %
Spain	7.26 %
France	6.25 %
Sweden	5.2 %
Netherlands	3.88 %
Italy	4%
Great Britain	2.8 %

Source: Al-Riffai, et al. (2010)

Access to liquid biofuel for rural households can also contribute to energy security in the household level and have a ripple effect on poverty alleviation. There are numerous examples where small-scale biofuel projects (e.g. for rural electrification) have contributed positively to the energy security of remote areas (FAO, 2009).

Box 1: Rural Electrification in Mali

FAO (2009) provides several examples of the environmental and social benefits that accrue from small-scale biofuel production. Such a case is rural electrification from jatropha vegetable oil (JVO) in Mali.

Trials of a small-scale pilot power plant that utilises JVO and diesel were performed in the Garalo commune in Mali. This small-scale project was initially launched with 5% JVO and 95% diesel in 2009 with plans of switching to 100% JVO by 2013. The trial was a success with almost 700 farmers and electricity subscribers currently getting electricity in rural Mali whose 99% rural population does not have adequate access to energy, including electricity. The feedstock was grown in the region's 326 ha of land previously used to grow cotton. Once scaled up, the area used to grow jatropha will approximately be 10,000 ha.

Apart from providing inexpensive and renewable energy, the project revealed several other co-benefits:

- **Human Capital**
  The farmers obtained new knowledge regarding the jatropha supply chain and profit means from making the switch to jatropha cultivation. The project also gave an opportunity for the creation of small business.

- **Natural Capital**
  Non-irrigated jatropha plantations have substituted irrigated cotton plantations. This shift has resulted in reduced water demand for agricultural activities.

- **Social Capital**
  Co-operatives have been set-up in the area, allowing the farmers to strengthen their social relationships. Constant access to electricity has also increased social activities and security due to street lighting.

- **Physical Capital**
  This project is one of the few integrated agriculture-energy projects in the region. The farmers consider electricity as a key infrastructure that will improve their livelihood in the future.

- **Financial Capital**
  The farmers that were hit during the cotton crisis have found a new source of capital through this new income generating activity. These farmers are now supplying a part of the local energy demand and as a result, they have a secure source of income.

However, given that current biofuel production practices (particularly for large-scale production) still rely greatly on fossil fuels for fertilisers, agrochemicals, electricity in biofuel plants, the long-term viability of biofuels following the current production practices and technologies is debatable.[13]

4.1.2 Food

Food crops are the most commonly used feedstocks for first generation biofuel. They can be staple crops (e.g. corn, wheat), or key vegetable oils (e.g. palm oil) while others, such as sugar cane and soybeans are important inputs to the food industry. Consequently, it has been suggested that greater biofuel production can compete with food production both directly (e.g. food crops diverted for biofuel production) and indirectly (e.g. competition for land and agricultural labour).

Fischer, et al. (2009) calculated that in 2007, 1.6% of the cultivated land globally was being used for biofuel feedstock production. When disaggregated, approximately 5.0%, 3.1%, and 2.4% of the cultivated area in North America, South America, and Europe respectively were appropriated for biofuel production (ibid). Simulations conducted by the same authors suggest that if the current 2020 biofuel mandates are to be met, biofuel production from cereals will significantly disrupt the production of food and feed particularly in developing nations. For this fear, some countries have prohibited the use of food crops for biofuel purposes. Hence, India has prohibited the use of edible crops for the production of biofuels, and instead use molasses and jatropha. Similarly, the main feedstock for production of bioethanol in China is low quality corn that is taken from the stockpiles, rather than high quality corn that is allocated for consumption purposes.

Biofuel production can also compete with other provisioning ecosystem services such as fiber and timber. For example, in India, jatropha plantations established on communal land have displaced part of the poor's household needs for food, fuel wood, fodder, and timber among others. In developing countries, such products commonly constitute the household's largest source of income, larger than cash crops and informal cash incomes, and can range from 20-40% or more of the total household income (Cavendish, 2000; Rajagopal, 2008; Dovie, 2003; Paumgarten and Shackleton, 2003).

The manifestation of the food-biofuel competition is the increase in food prices. Even though the exact mechanisms of how biofuels affect food prices cannot be easily delineated, it is believed that biofuel subsidies in developed countries, globalised trade, speculation and high fossil fuel prices play a significant role (Runge and Senauer, 2008; RFA, 2008; Mitchell, 2008). Various sources have estimated that biofuels might have contributed up to 30% of the weighted average increase in cereal prices from 2000-2007[14]. Figures 4 and 5 illustrate the consistent increase in commodity prices and the harvested area for the biofuel crops of maize and sugar cane. Food price increases affect all aspects of human well-being, such as security, basic materials for good life, health, and social cohesion.

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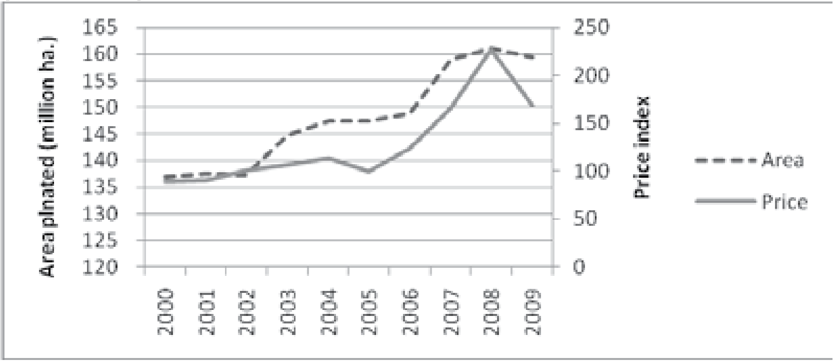
[13] There can be other benefits from biofuel production, such as employment, which the authors are addressing in research in progress.

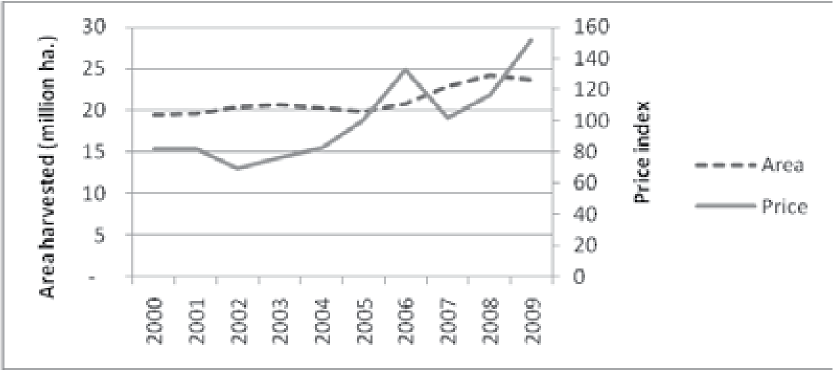
[14] High food prices can disproportionately affect the urban poor (RFA, 2008). It also can influence social unrest, such as the food riots that took place in several countries such as Egypt, Mexico, Indonesia, and several Sub-Saharan African nations, among several others (Runge and Senauer, 2008).

Figure 4: World Harvested Area and Commodity Price for Maize (2000-2009)



Source: FAOstat, IMF. Price data: Maize (corn), Price Index U.S. No.2 Yellow, FOB Gulf of Mexico, U.S. price.

Figure 5: World Harvested Area and Commodity Price for Sugar (2000-2009)



Source: FAOstat, IMF. Price data: Commodity Sugar Index includes European, Free market, and U.S. Price Indices.

4.1.3 Freshwater Services

Biofuel production can affect the ecosystem service of freshwater through overexploitation and degradation, mainly through pollution. It is feared that increased feedstock cultivation and biofuel production will increase both water consumption and water pollution.

4.1.3.1 Water Depletion

Currently, the total water requirement[15] for first generation biofuel production and particularly for irrigated feedstocks is quite modest when compared to the water appropriated for food production (e.g. CA, 2007)[16]. However, greater biofuel production might result in increased water consumption (e.g. de Fraiture, et al., 2008; Berndes, 2002). This might result in a

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[15] The water used within plants for the transformation of the feedstock to the final feedstock is much lower than for the production of the feedstock itself (IATP, 2008).

[16] In cases where the feedstocks are primarily rain fed (e.g. rapeseed in Europe), then irrigation is even smaller (de Fraiture, et al., 2008).

competition between food and biofuel production not only for land and labour (refer to Section 3.1.2) but also for water. This might be potentially serious for countries such as China and India that have mandated the use of biofuels but are under increasing water stress (e.g. de Fraitute, et al., 2008). For example, the bioethanol production from molasses is very water intensive and a shift towards greater biofuel production might affect the water supply in countries such as India, which are using molasses as a feedstock and are under proven water stress (Kojima and Johnson, 2005).

It has also been suggested that a potential shift towards greater biofuel production can have significant impact on water consumption even in areas that are not currently facing significant water stress (e.g. NAP, 2010; Berndes, 2002). For example, embodied water analysis has shown that current bioethanol production practices in the US, e.g. extensive irrigation for corn, already results in the depletion of vulnerable aquifers with these trends being most prevalent in states that are expected to face water shortages in the future (e.g. Chiu, et al., 2009).

Interestingly, the water footprint analysis[17] has shown that for most biofuel feedstocks, the total water footprints are consistently larger in developing nations (Gerben-Leenes, et al., 2009a; 2009b). At the same time, the water footprint of biofuels can be 70-400 times higher than that of conventional fossil fuels (Gerbens-Leenes, et al., 2009b), and it is more water-efficient to use biomass to produce bioelectricity than to produce biofuels (Gerbens-Leenes, et al., 2009a). In fact, the total water requirement of biofuel energy is consistently larger, up to two degrees of magnitude, than the water requirement of different forms of conventional energy generation, including hydropower (ibid).

4.1.3.2 Degradation of Water Quality

Feedstock production relies greatly on fertilisers and agrochemicals that can enter water bodies and potentially disrupt ecosystem functioning. At the same time, biofuel production practices can produce effluents with high toxicity and Biological Oxygen Demand (BOD). For example, Gunkel, et al. (2007) have highlighted the significant impact of sugar cane production and processing on water quality in Brazil[18].

High levels of nitrogen fertiliser used for sugar cane crops can lead to the excessive accumulation of nitrogen into aquatic systems. Filoso, et al. (2003) reported high rates of nitrogen export into rivers draining watersheds such as the Piracicaba and Mogi river basins, which are heavily cultivated with sugar cane. Nitrogen export was much higher in primarily agricultural sub-catchments than in sub-catchments where forested and pasture land dominated the landscape (ibid). In fact, Martinelli and Filoso (2008) have identified sugar cane expansion as one of the main drivers of increased fertiliser use across Brazil. Indeed, sugar cane cultivation consumes large amounts of fertilisers and constitutes one of the most fertiliser intensive agricultural practices in Brazil (FAO, 2004b). Similarly, oil palm plantations are also fertiliser intensive and consume by far the largest amount of fertilisers than any

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[17] The water footprint is expressed in m3 (of water consumed) per GJ (of energy produced) and depends on numerous factors such as the type of crop, the agricultural production system and the climate (Gerbens-Leenes, et al., 2009b). However, even within the same country, the water requirement of biofuel production can depend on other factors such as the regional water use practices (Chiu, et al., 2009).

[18] Water heating, acidification, increased turbidity, oxygen imbalance, and increased coli form bacteria levels in the Ipojuca River (Brazil) were associated with the sugar cane industry.

other crop in Malaysia (FAO, 2004b; FIAM, 2009) and the third largest in Indonesia (FAO, 2005). Finally, Donner and Kucharik (2008) suggest that if US corn cultivation increases in order to meet the 15-36 billion gallons of renewable fuel by 2022 without changing current cultivation practices, then significant added nitrogen loading should be expected along the Mississippi River, subsequently increasing hypoxia in the Gulf of Mexico.

Lehtonen (2009) collected evidence on the numerous agrochemicals that are being used in sugar cane production and their potential negative effects on the environment and on the human health (e.g. the agrochemical 2,4-D which is a possible carcinogen, groundwater pollutant, and endocrine disruptor), while Lara, et al. (2001) have shown the prevalence of agrochemicals in areas that are used for sugar cane cultivation. For example, contaminants such as atrazine, a herbicide used in sugar cane crops, and heavy metals like copper, were found in water samples and stream bed sediments collected from waterways flowing through areas of extensive sugar cane cultivation (Carvalho, et al. 1999, Azevedo, et al. 2004, Corbi, et al. 2006). Martinelli and Filoso (2008) cite several case studies that associate sugar cane burning practices with the acidification of streams/rivers and the detection of Polycyclic Aromatic Hydrocarbons in sediments in lakes in São Paulo State. As a legume, soybean cultivation requires little nitrogen inputs but does require agrochemicals to combat diseases, weeds, and pests. The concentration of these agrochemicals in water bodies surrounded by soybean plantations may also accumulate in fishes caught for human consumption (Fearnside, 2001).

Further down the production chain, biofuel production has been identified as a major source of water pollution. Waste products and by-products of the industrial processing of sugar cane and palm oil into ethanol and crude palm oil respectively are highly polluting and can have severe environmental impacts if released without proper treatment. Palm oil mill effluent (POME) and vinasse from sugar cane distillation are rich in organic matter and contribute to eutrophication and depletion of dissolved oxygen levels in aquatic systems if left untreated (Donald, 2004; Martinelli and Filoso, 2008). POME is characterised by high levels of BOD[19] with approximately 2.5-3 tons of POME being produced for each ton of palm oil (Wu, et al., 2010). Effluent from sugar cane mills is also rich in BOD with 12-13 liters of vinasse being generated for each liter of ethanol (Martinelli and Filoso, 2008). Despite the existence of present technologies to treat mill effluents, it is not uncommon for leakages and intentional discharge from small mills, leading to adverse impacts on the aquatic ecosystems (Martinelli and Filoso, 2008; Sheil, et al. 2009)).

However, despite these negative effects, there is evidence that biofuel production can sometimes be beneficial for freshwater ecosystem services. For example, it has been shown that willow biofuel feedstock can be used to purify wastewater (Börjesson and Berndes, 2006). Gopalakrishnan et al. (2009), have suggested that bioenergy crops can be used to restore contaminated aquifers and marginal lands. Also it has been suggested that POME and sugar cane mill effluent can be used for oil palm and sugar cane irrigation, respectively. However the other environmental co-benefits of such practices are debatable.

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[19] POME has BOD of 21500-24500 mg/L, which is several times higher than that of sewage water.

4.2 Regulating Services

4.2.1 Climate Regulation

Biofuels can emit GHG during several stages of their life cycle (Hess, et al., 2009; Delucchi, 2006). Several LCAs have shown that biofuels can emit less GHG during their whole life cycle and thus be seriously considered as a potent climate change mitigation measure (refer to Table 3 and 4). GHG emissions savings are quite significant and can sometimes reach 80-100% of emissions from conventional fossil fuels. Such GHG savings are significantly higher than the targets specified by national and international biofuel policies including the 35% GHG saving target laid by the European Union (EC, 2009).

However, in most LCAs (such as the ones mentioned in Tables 3 and 4), the impact of Land Use and Cover Change (LUCC) on the emission of GHG is not properly accounted for. Biofuel expansion can induce LUCC directly and indirectly. Considering that LUCC has been identified as a major "emitter" of GHG, biofuel production in general and feedstock production in particular can be net GHG emitters.

Box 2: Indebting the Future?

Palm oil plantations are expected to be net carbon sinks and protect the soil only if they are established on crop/grassland and not on forested or peatland areas (Danielsen, et al., 2009; Verwer, et al., 2008). Danielsen, et al. (2009) calculated that depending on the forest clearing method used, it would take 75-93 years for an oil-palm plantation to compensate the carbon lost during the conversion of the initial forest (600 years when oil-palm is planted on peatland). When grassland is converted to oil-palm, the compensation occurs in mere 10 years.

Fargione, et al. (2008) report similar findings for palm biodiesel production from cleared tropical rainforest and peatland in Indonesia and Malaysia. In the Brazilian context, Fargione, et al. (2008) calculate that the time required to repay the biofuel carbon debt would be 17 years (sugar cane substituting woodlands), 37 years (soybean substituting grassland) and 319 years (soybean substituting tropical rainforest). Gibbs, et al. (2008) have calculated carbon payback times for several feedstocks in the tropics with their results showing that following present practices it will take decades to offset the carbon lost during the conversion of productive tropical ecosystems (forests, woody savannahs and grassland) in South America, Africa, and Asia.

Indirect land impacts can also significantly affect GHG emissions. Lapola, et al. (2010) have calculated that by 2020, biofuel expansion in southern Brazil might create a carbon debt of up to 250 years mainly due to indirect LUC (direct LUC will also contribute but not significantly). In their model, they suggest that replacement of rangeland in southern Brazil with sugar cane cultivation might push the rangeland frontier in the Amazon and cause significant deforestation (ibid).

Biofuel expansion can also affect regional climate as a result of land cover conversion. For example, Georgescu, et al. (2009) found that land conversion from one crop type to another for biofuel expansion in the US Corn Belt may affect regional climate as a result of the changes in energy and moisture balance of the land surface upon conversion to biofuel crops.

4.2.2 Air Quality Regulation

Atmospheric pollutants are emitted during several processes during a biofuel's life cycle. Feedstock cultivation can be a particularly polluting stage with atmospheric pollutants being emitted not only from activities such as fertilisers use, land-clearing through fire and other feedstock-specific activities such as sugar cane burning (to assist harvesting), but also from the feedstock itself.

Biofuel feedstocks, like all other plants, are emitters of Volatile Organic Compounds (VOCs) and particularly of isoprene. Even though there is limited knowledge regarding VOC emissions from biofuel feedstock, there is a concern that greater biofuel production, especially from tree plantations such as palm oil, might result in greater VOC emissions (Royal Society, 2008; Hewitt, et al., 2009). Hewitt, et al. (2009) have shown that indeed, greater amount of VOC and nitrogen oxides (NOx) emissions, which are tropospheric ozone precursors (O_3), are emitted from oil palm plantations than from rainforests[20]. NOx are mainly emitted mainly through the application of fertilisers and combustion in farm activities, such as mechanised agriculture (Hess, et al., 2009).

Burning[21] is a common crop management practice in Brazil for facilitating the harvesting of sugar cane and has been used to clear natural vegetation for oil palm and soybean expansion in Indonesia and Brazil (Casson, 2003; Martinelli and Filoso, 2008; Sheil, et al., 2009). This method is not only a quick and inexpensive alternative to clear land (Guyon and Simorangkir, 2002), but it leads to forest degradation which allows oil palm companies to acquire land use permits more easily (Casson, 2000). Oil palm expansion has been partially responsible for the devastating 1997-1998 forest fires in Indonesia, where satellite imagery showed oil palm companies initially starting the fire to clear land (Dennis, et al., 2005). The dry conditions brought about by the El Niño phenomenon exacerbated the fires which burned 11.6 million ha of land, more than half of which were montane, lowland, and peat forests (Tacconi, 2003). In Brazil, the El Niño effect also led to serious droughts in the North and North-East, and fires ignited in the savanna areas for pasture and agricultural crops such as soybean blazed out of control, contributing to serious forest fires in the North (Casson, 2003).

The burning of the straw and leaves of sugar cane greatly facilitates the process of harvesting and drives out snakes, which may pose a danger to the cane cutters (Martinelli and Filoso, 2008). However, sugar cane burning is a major source of particulate matter with aerodynamic diameter <2.5 μm (PM2.5) and <10 μm (PM10) (Cancado, et al., 2006; Lara, et al., 2005; Martinelli, et al., 2002; Castanho and Artaxo, 2001), Polycyclic Aromatic Hydrocarbons (PAHs) (Martinelli and Filoso, 2008), and NOx (Oppenheimer, et al., 2004). At the same time, sugar cane burning can lead to soil temperature increase, decrease in soil water content, and soil degradation (Dourado-Neto, et al., 1999; Oliveira, et al., 2000; Tominaga, et al., 2002).

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[20] NOx is mainly emitted from agricultural system, i.e. use of fertilisers and vehicle combustions and facilities, while VOC emissions are emitted from the oil palm trees themselves.

[21] Biomass burning has been identified as a major source of atmospheric pollution, and GHG emissions significantly affect atmospheric chemistry and biogeochemical cycles, among other impacts (Bytnerowicz, et al., 2008; Crutzen and Andreae, 1990).

Further down the chain, Delucchi (2006) found that US corn ethanol and soy biodiesel release higher levels of carbon monoxide (CO), nitrogen dioxide (NO_2), non methane organic compound (NMOC), sulphur dioxide (SO_2), and particulate matter (PM) emissions in their life cycle in comparison to conventional gasoline. In particular, fuel production, feedstock recovery, cultivation, and fertiliser manufacturing were identified as those processes responsible for the bulk of the pollutant emission.

Atmospheric emissions associated with biofuel production and combustion can also severely affect the human health. Jacobson (2007) suggests that if E85 was to substitute conventional gasoline by 2020, ozone-related mortality and other health effects associated with the direct atmospheric emissions of bioethanol will increase by 9% in Los Angeles and by 4% in the rest of the US. Hill, et al. (2009) have shown that the health-related costs associated with the emission of PM2.5, a potent health hazard, from corn-ethanol during its whole life cycle is comparable, and in most cases greater than the costs associated with PM2.5 emissions from conventional gasoline[22]. Moreover, Cancado, et al. (2006) have shown that respiratory related hospital admissions are increasing during the sugar cane burning season in parts of Brazil. These trends are more evident for the admission of children with two to three times more hospital admissions during the burning season. As already mentioned, land clearing by fire is a common method used in oil palm plantations in South East Asia. The forest fire induced air pollution health effect in South East Asia have been thoroughly documented in sevearl academic literature, (e.g. in Frankenberg, et al., 2005; Sastry, 2002; Emmanuel, 2000).

However, biofuels can have positive impacts on ambient air quality. For example, the introduction of biofuels in Brazil has been credited with the improvement of air quality in the city of São Paulo. The introduction of motor vehicles which run on ethanol and the associated incentives led to the gradual de-phasing of older, more polluting, and less energy efficient vehicles. In this respect, biofuel introduction as an alternative transport fuel can be viewed as a potential opportunity for the introduction of cleaner technology, something that can have ripple effects in ambient air quality, particularly in cities situated in the developing world.

4.2.3 Erosion Regulation

Martinelli and Filoso (2008) mention that sugar cane cultivation is a significant driver of soil erosion in Brazil. In fact, in several areas of the state of São Paulo, high erosion rates have been observed in land that is consistently under sugar cane cultivation (ibid). It has been estimated that during sugar cane production, bare soils are exposed to intense winds and rains during management practices, which can result in soil erosion rates of up to 30 tons/ha/year (Sparovek and Schnug, 2001; Martinelli and Filoso, 2008). Soil erosion as a result of soybean cultivation amounts to similar rates of losses between 19 and 30 tons/ha/year depending on soybean management practices, land aspect, and soil type (Tomei and Upham, 2009). For example, soybean cultivation in Argentina exhibits greater soil erosion potential and greater negative effect on soil nutrients than switchgrass (Van Dam, et al., 2009). Soil erosion potential is further increased if soybean is cultivated at degraded grassland rather than abandoned cropland (ibid). Mature oil palm plantations in Malaysia have a soil erosion rate of approximately 7.7 to 14 tons/ha/year (Hartemink, 2006). Soil

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[22] Costs from cellulosic ethanol emissions are much lower.

erosion in oil palm plantations can be even more serious in the early years when a complete palm canopy has not yet been established, which is why maintaining a legume crop cover is important to protect against soil erosion (Corley and Tinker, 2003).

de Vries, et al. (2010) ranked the most commonly used biofuel feedstocks from lower to higher levels of soil erosion hazard as follows: cassava, soybean, sugar cane, sorghum, corn, sugar beet, winter wheat, oil palm, and winter rapeseed. It is recognised that this is an indicative ranking that can depend on the characteristics of the soil itself and the cultivation method adopted among other factors.

On the other hand, feedstocks that can be grown in marginal lands such as jatropha can improve soil quality and control erosion in marginal lands (Achten, et al., 2008; Gmunder, et al., 2010). It is interesting to note that agricultural practices such as sugar cane burning, which can have negative effects on ambient air quality and human health, can reduce the risk of erosion if the residues are left on the soil (Smeets, et al., 2008).

4.3 Cultural Services

The cultural services provided by ecosystems (e.g. spiritual, aesthetic, educational, and recreational services) are sometimes highly valued in monetary terms (MA, 2005). For local communities and indigenous people, such services frequently form an important element of their culture and can often threaten several factors such as Land Use and Cover Change (LUCC) (MA, 2005). For instance, certain plants are important ceremonial elements, while high biodiversity agriculture (e.g. corn) can have important aesthetic and cultural value that cannot be provided by monoculture cropping systems, such as in developing countries. Of course, this is not a phenomenon in developing countries alone. Sometimes, maintaining the traditional land use and the local customs is held more important than the material gains even in industrialised countries such as among small-scale farmers in the southern US (e.g. Raish and McSweeney, 2003).

Changes in ecosystem conditions can alter the values that people derive from cultural ecosystem services (Rodriguez, et al., 2006). Even though in some occasions, ecosystem change may increase cultural value[23]; however, it is most likely that the opposite phenomenon might occur. Biofuel induced LUCC may diminish the cultural value people receive from landscapes and ecosystems, by destroying habitat and displacing traditional crops (Friends of the Earth, 2008). Feedstocks, such as oil palm, are frequently planted on forest land and as a result, they lead to deforestation (refer to Section 5.1). It has been suggested that biofuel induced deforestation can affect indigenous people disproportionately. For instance, almost half of Indonesia's population of 216 million depends on forests and ecosystem goods and services with approximately 40 million of these people being indigenous and having already been affected (Tauli-Corpuz and Tamang, 2007).

At the same time, several biofuel feedstocks are assessed for their invasiveness (Bradley, et al., 2006; Raghu, et al., 2006) (refer to Section 4.3). Invasive alien species may eliminate traditional plant species with high cultural value, with potentially severe impacts especially for the poor in tropical countries (MA, 2005).

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[23] E.g. in the Dutch constructed lowlands or as exhibited in high land rents surrounding built environment projects (MA 2005a: Peterson, et al., 2003).

Finally, marginal land has been targeted as the most appropriate land for expanding biofuel production in a sustainable manner. Economically, land is marginal if it is not profitable, e.g. when crop prices and yield do not cover production cost (Dale, et al., 2010). However, marginal land often provides other ecosystem services including space for economically and politically marginalised populations with the cultural and spiritual benefits derived from the land that are not always acknowledged when assessing the costs and benefits of biofuel production (Dale, et al., 2010).

5. Impacts on Biodiversity

Biodiversity underpins all ecosystem services, and is defined as the variability of living organisms, as well as the ecological complexes hosting them. This includes diversity within and between species such as animals, plants, and microorganisms (MA, 2005).

While biofuel production (particularly feedstock cultivation) may under certain conditions offer wildlife habitat (Godfray, et al., 2010), it is considered to be a potentially significant emerging threat to biodiversity (Groom, et al., 2008). Six main direct drivers of biodiversity loss have been identified in the academic literature: habitat loss, overexploitation, invasive alien species, disease, pollution, and climate change, as well as the interactions between them (MA, 2005). Biofuel production has been linked to four of these drivers, namely habitat destruction, invasive alien species, pollution, and climate change. Although the biodiversity impacts are case specific, Table 6 gives an overview of the potential impact of the most common biofuel feedstocks.

Table 6: Feedstock Specific Impacts on Biodiversity

Feedstock	Land Usually Converted or Used	Impact on Biodiversity
Oil palm	Virgin forest	Very high
Sugar cane	Grassland/cultivated land	High
Corn	Cultivated land	High
Cassava	Cultivated land/grassland/forest	Neutral
Rapeseed	Cultivated land	High
Soybean	Grassland/cultivated land/forest	Very high
Jatropha	Grassland/cultivated land	Neutral

Source: Adapted from (Fischer, et al., 2009)

5.1 Habitat Loss

Of these four drivers, biofuel induced habitat destruction is perhaps considered to be the greatest threat to biodiversity. Conversion of natural habitats into monocultures, by definition, implies a drastic loss of biodiversity and change in the composition of species communities in the area. Currently, biodiversity in the tropical regions of South East Asia and Latin America is under the greatest threat of biofuel expansion, namely from oil palm, sugar cane, and soybean expansion (Koh and Wilcove, 2007, 2008, 2009; Wilcove and Koh, 2010).

Box 3: Assessing the Link to Deforestation in Indonesia and Malaysia

Koh and Wilcove (2008), report that oil palm plantations in Malaysia and Indonesia have mainly replaced primary and secondary tropical forest rather than pre-existing cropland. Based on land-cover data compiled by the Food and Agricultural Organisation of the United Nations, Koh and Wilcove (2008) calculated an expansion of 1.8 million ha of oil palm in Malaysia and 3 million ha in Indonesia between 1995 and 2005. Approximately 55-59% of this oil palm expansion in Malaysia and at least 56% of that in Indonesia occurred at the expense of primary or logged forests. Due to this massive LUCC induced by oil palm expansion, oil palm plantations are believed to have a significant impact on biodiversity in a region that contains a significant portion of the planet's remaining tropical forests as well as two of the world's twenty-five biodiversity hotspots.

It has been hypothesised that oil palm plantations cause biodiversity decline because such habitats are structurally less complex than primary forests, have a shorter lifespan and are major landscape fragmentation factors (Fitzherbert, et al., 2008). Reviews of academic studies have shown that oil palm plantations indeed contain much fewer species and less than half as many vertebrate species as primary forests (e.g. Fitzherbert, et al., 2008; Danielsen, et al., 2009) (refer to Table 7). For example, it has been shown that oil palm plantations harbour fewer bird (Peh, et al., 2005) and butterfly (Hamer, et al., 2003; Dumbrell and Hill, 2005) species than primary forest, logged forest, and rubber plantations. Forest bird species declined by 73%-77% (Koh and Wilcove, 2008) and only 10% of mammal species were detected in oil palm plantations (Maddox, et al., 2007). Endangered species such as the Sumatran tiger (Panthera tigris sumatrae), tapirs (Tapirus indicus), and clouded leopards (Neofelis nebulosa) were never recorded in oil palm plantations; most mammals even preferred marginal and heavily degraded landscapes, such as shrublands, to oil palm (Maddox, et al., 2007). Mammals that do occur in oil palm plantations tend to be of low conservation value, and are dominated by a few generalist species such as the wild pig (Sus scrofa), bearded pig (Sus barbatus), leopard cat (Prionailurus bengalensis), and common palm civet (Paradoxurus hermaphroditus) (Danielsen, et al., 2009 and Maddox, et al., 2007).

Table 7: Species Richness in Natural Forests and Oil Palm Plantations

Study	Country	Taxonomic Group	Number of Species Forest	Plantation	Shared
Room, 1975	Papua N. Guinea	Ground foraging ants	49	29	11
Chang, et al., 1997	Malaysia	Mosquitoes	6	6	6
Chung, et al., 2000	Malaysia	Subterranean beetles	306	64	-
Chung, et al., 2000	Malaysia	Arboreal beetles	174	40	-
Chung, et al., 2000	Malaysia	Ground beetles	557	75	-
Bruhl, 2001	Malaysia	Ants (site 1)	20	11	6
Bruhl, 2001	Malaysia	Ants (site 2)	8	15	6
Bruhl, 2001	Malaysia	Ants (site 3)	4	8	1
Liow, et al., 2001	Malaysia	Bees	8	17	-
Benedick, 2005	Malaysia	Butterflies	26	12	1
Davis and Phillips, 2005	Ghana	Dung beetles	25	20	7
Hassal, et al., 2006	Malaysia	Terrestrial isopods	8	4	0
Chey, 2006	Malaysia	Moths (site 1)	75	85	28
Chey, 2006	Malaysia	Moths (site 2)	133	73	28
Chey, 2006	Malaysia	Moths (site 3)	78	90	11
Koh and Wilcove, 2008	Malaysia	Butterflies	63	-	12
Danielsen and Heegaard, 1995	Indonesia	Birds	67	17	3
Danielsen and Heegaard, 1995	Indonesia	Bats	8	1	1
Glor, et al., 2001	Dominican Republic	Lizards	6	5	3
Scott, et al., 2004	Indonesia	Small mammals	5	3	2
Aratrakorn, et al., 2006	Thailand	Birds	108	41	21
Peh, et al., 2005, 2006	Malaysia	Birds	152	-	36
Maddox, et al., 2007	Indonesia	Medium/large mammals	38	4	4

Source: Adapted from Danielsen, et al., 2009.

On the other hand, invertebrate taxa showed even greater variation between oil palm plantations and natural forests (Fitzherbert, et al., 2008). For example, the conversion of forests to oil palm caused forest butterfly species to decline by 79%-83% (Koh and Wilcove, 2008); whereas ants, moths, and bees showed a higher total species richness in oil palm than forests (Danielsen, et al., 2009). Nevertheless, studies consistently showed a dominance of non-forest invertebrate species in oil palm plantations (Danielsen, et al., 2009). Comparing across both vertebrate and invertebrate taxa, a mean of only 15% of species recorded in primary forest could be found in oil palm plantations (Fitzherbert, et al., 2008). Not surprisingly, plant diversity within oil palm plantations was diminished compared to forests due to regular maintenance and replanting (every 25 to 30 years) of oil palm fields (Fitzherbert, et al., 2008; Danielsen, et al., 2009).

In Brazil, the area of soybean expansion increased dramatically by 10 million ha, from 11.6 million to 22.9 million ha between 1995 and 2005 (FAO, 2010). Successful expansion of soybean has been driven by a biotechnological breakthrough, namely the development of soybean-bacteria combinations with pseudosymbiotic relationships, which allows soybeans to be planted with little or no application of nitrogen fertilisers (Fearnside, 2001). Although much of this soybean expansion has occurred on non-forested lands, particularly in the Cerrado, this natural grassland ecosystem nonetheless contains high concentrations of endemic and threatened species (Fearnside, 2001).

Biodiversity loss from soybean and sugar cane production has not been as well studied as oil palm but can be expected to be significant by virtue of large-scale natural habitat conversion (Fearnside, 2001).

Box 4: Soybean Expansion in the Cerrado Savanna, Brazil

The Cerrado is the largest savanna region in South America and contains a rich diversity of different vegetation types, from tree and scrub savanna, grasslands with scattered trees and patches of dry, closed canopy forests known as the Cerradão (Conservation International, 2010). This region contains a large number of plant (10,000 species) and animal species (2,000 species), including many endemic species such as the maned wolf (Chrysocyon brachyurus), the giant armadillo (Priodontes maximus), and the giant anteater (Myrmecophaga tridactyla) (Conservation International, 2010). The ecoton between forest and cerrado is also rich in endemic plant species (Fearnside and Ferraz, 1995). Unfortunately, this ecosystem has also been widely cleared for soybean expansion as it is the least protected ecosystem in Brazil, with only 1.5% protected within federal reserves (Casson, 2003).

Sugar cane expansion in Brazil has almost doubled from 4.5 million ha in 1995 to 8.1 million ha in 2008, with a rapid increase of 2.3 million ha between 2005 and 2008 (FAO, 2010). Martinelli and Filoso (2008) cite several cases that show how the destruction of riparian ecosystems due their conversion to sugar cane plantations can lead to biodiversity loss. Interestingly, the destruction of such riparian ecosystems results in reduced water quality that can further affect biodiversity and human well-being (ibid). However, it is the future expansion of sugar cane agriculture that can pose an even more significant threat to biodiversity. It is predicted that future sugar cane expansion for ethanol export in the Brazilian south-east can affect directly and indirectly the Cerrado (Smeets, et al., 2008; Sparovek, et al., 2010) and the Amazon (Lapola, et al., 2010). The expansion of biofuel industries is not the only cause of habitat loss in these areas; other causes include large-scale commercial logging, pulp and paper industries, cattle ranching, shifting cultivation, mining, urban development, and agricultural expansion of other crops (Angelsen and Kaimowitz, 1999). However, growing global demand for palm oil, soybean, and sugar cane for biofuels will likely exacerbate deforestation in these regions over the next decade (IATP, 2008).

Hellmann and Verburg (2010) have shown that the future biofuel expansion in the EU as mandated by existing legislation can impact biodiversity throughout the continent by 2030. LUCC is a key driving force, and they estimate that even though the direct LUCC effects of biofuels will be negligible, the indirect effects of biofuel expansion will be far more significant (ibid). McDonald, et al. (2009) have estimated under several different scenarios that bioenergy, particularly biodiesel from soybeans and ethanol from corn and sugar cane, will consistently have the largest impact on US land use by 2030. Most of this new area will be directly claimed in temperate forest (deciduous and conifers) and temperate grassland, and will amount to between 141000 km^2 and 247000 km^2 (ibid). As a result, significant impacts on biodiversity can be expected.

5.2 Interaction with Other Frontier Opening Activities

The development of biofuel plantations is associated with other drivers of habitat loss and degradation such as industrial activities like logging or cattle ranching and the building of infrastructure such as roads and waterways. This increases the accessibility of natural resources for further exploitation and heightens the level of fragmentation and isolation of remnant natural habitats. Oil palm plantations have been associated with logging companies as the profits obtained from the sale of timber can help cover part of the establishment costs of an oil palm plantation (Casson, 2000). In cases where companies seek short-term profits or are unwilling to take the risks in developing oil palm industries in infrastructure-poor regions (e.g. Papua and Kalimantan), application for licenses to establish oil palm estates provide a loophole for these companies to clear-cut forests without the use of sustainable management practices for the timber extracted (Casson, 2000). This explains why less than 1 million ha out of 5.3 million ha of land allocated to oil palm development have actually been planted with oil palm in Kalimantan (Casson, et al., 2007).

The expansion of soybean in Brazil has been linked to both charcoal production and cattle ranching (Casson, 2003). For example, through the establishment of previously lacking infrastructure such as road networks, soybean expansion provides easier access to Cerrado trees, which are felled and used by the Brazilian steel industry for charcoal production. Profits generated by selling the Cerrado trees to charcoal producers have helped soybean farmers to further expand their farms. The degradation of gallery forests due to the extraction of such trees has raised concern as these forests provide a corridor that links the Amazon and the coastal forests with the Cerrado and is an important habitat for several endemic fauna (Tengnäs and Nilsson, 2003). The advancement of large-scale mechanised soybean farms as a result of government policies and soybean technologies pushed small-scale farmers into the Amazonian frontier where agricultural expansion and pasture development (i.e. cattle ranching) took place at the expense of forests (Skole, et al., 1994; Schneider, et al., 2000). Fearnside (2001) describes how soybean expansion has led to major infrastructure developments in Brazil and highlights the potential for habitat exploitation due to greater accessibility in the region.

5.3 Other Stresses on Biodiversity: Pollution, Invasive Alien Species and Climate Change

Further down the biofuel production chain, biofuel industries that engage in poor production practices could also cause indirect ecological damage through environmental pollution and degradation. Section 4.1.3.2, 4.2.2, and 4.2.3 described that inappropriate management practices such as intensive usage of fertilisers and pesticides as well as using fires for land clearing could lead to environmental problems such as soil degradation, and water and air pollution, which in turn could lead to long-term ecological impacts in the tropics. For soybean and sugar cane, which are both annual crops, the ecosystem of the agricultural landscape is disrupted yearly and requires high inputs of fertilisers, pesticides, and weed control to maintain high levels of production (Casson, 2003; Martinelli and Filoso, 2008). Surface run-off as a result of soil erosion brings organic matter and agro-chemicals into aquatic systems, which can lead to the deterioration of aquatic habitats and affect the biodiversity downstream.

Currently, there are fears that certain biofuel crops have the potential to become invasive (e.g. Pyke, et al., 2008; Raghu, et al., 2006; Buddenhagen, et al., 2009). Even though perennial grasses are mostly associated with invasiveness, certain first generation biofuels can become invasive. Such an example is the case of jatropha, which has been designated as invasive and thus banned from planting in parts of Australia while it is being tested for potential invasiveness in other parts of the world (e.g. DAF, 2007).

Finally, in the long-run, biofuel affect climate change by either mitigating green house gas emissions or actually causing higher such emissions. Consequently, biofuel has a stake in climate change induced biodiversity loss, by either increasing or decreasing such stress. .

Reconciling biofuel expansion with biodiversity conservation and the preservation of ecosystem services is not a straightforward process due to the links between the biofuel industry and both the agricultural and energy sector. A careful assessment of land use allocation options and major restructuring of the agricultural management system may be required for biofuel expansion to proceed with little or no environmental costs. Additionally, the development of energy efficient transportation systems and the advancement of second and third generation biofuels will help alleviate demand for conventional biofuel feedstocks. However, these actions will require a considerable amount of time, resources, and long-term commitment from society. From an ecosystems services perspective, there is an added urgency to also work on immediate solutions to minimise the loss of threatened ecosystem services due to biofuel expansion. Some of the most promising response options are listed below.

These alternatives address both the pressure on ecosystem services and on biodiversity. Even with the adoption of all of these responsible management practices, oil palm and other biofuel plantations will still have a considerable residual impact on the environment. In the case of biodiversity, biodiversity offsets which is the calculation of the residual impact and paying off by conserving another area natural habitat, have been proposed to compensate for some of the environmental damage incurred by the plantation (Maddox, 2007).

6. Response Options

6.1 Using Degraded Lands

Competition for land used for fuel, food, fodder, and forests is at the core of the biofuel debate. For example, the replacement of biodiverse habitats with monocultures for feedstock production is, without a doubt, the greatest threat to biodiversity. Clearly, the obvious solution is to avoid planting biofuel feedstocks on native natural habitats (IATP, 2008). Moreover, as many of the regions being targeted for biofuel production contain high levels of endemic flora and fauna, the loss of these habitats would result in global extinctions of numerous species (Myers, et al., 2000). The removal of critical ecosystems for biofuel production negates any benefits accrued from the use of biofuels over fossil fuels (Gibbs, et al., 2008).

Some researchers have argued for the use of degraded lands for biofuel cultivation. However, this proposal is not as straightforward as it seems. Should the definition of 'degraded' be stretched to include secondary logged forests? Biodiversity losses will still continue, as such forests still preserve a significant portion of primary forest biodiversity (Dunn, 2004; Barlow, et al., 2007; Koh and Wilcove, 2008). In some cases, degraded lands have been shown to be utilised by high conservation value species like the Sumatran tiger and the value of their biodiversity cannot be judged simply based on the vegetation structure and characteristic of the landscape (Maddox, 2007). Significant amounts of fertilisers and weed control are also required to convert alang-alang grasslands into oil palm plantations (Fairhurst and McLaughlin, 2009), and insecure land tenure regarding degraded lands pose big risks to any biofuel feedstock producing company investing in plantation development (Cotula, et al., 2008). Degraded lands can also be open to other land uses such as restoration ecology, cattle ranching, settlements and urbanisation, hence strategies to expand biofuel production into degraded lands must be approached with caution.

6.2 Improved Plantation Management Practices

To partially reconcile biofuel expansion with the maintenance of other ecosystem services and biodiversity conservation, a set of compromises regarding land competition and a great deal of collaboration with biofuel producers will be required. It will be imperative for environmental groups to engage with biofuel producers of various levels – from small-scale farmers to large private companies, to help producers and growers recognise the value and importance of biodiversity in the unique habitats where they grow their biofuel crops. As soybean and sugar cane are annual crops, little can be done to preserve biodiversity within the agricultural landscape when great disturbances to the landscape occur during harvest seasons. Fewer disturbances occur in oil palm plantations which use perennial crops that last for a period of 25 to 30 years.

In these artificial habitats, Koh (2008a) demonstrated that various local vegetation characteristics such as percentage ground cover of weeds, epiphyte prevalence, and presence of leguminous crops can help enhance native bird and butterfly species richness. On a landscape level, the percentage of natural forest cover was able to explain 1.2-12.9% of variation in butterfly species richness and 0.6-53.3% of variation in bird species richness. Adoption of such measures is not just important to make oil palm plantations more hospitable for native biodiversity. Bird-exclusion experiments in oil palm plantations have shown a significant increase in herbivory damage by herbivorous insects, providing an economic justification for conserving remnant natural habitats for this natural pest control service (Koh, 2008b). Many oil palm plantations have also included integrated pest management systems which favour the use of non-chemical pest control methods such as the establishment of "beneficial plants" (e.g. Euphorbia heterophylla) to attract insect predators and parasitoids of oil palm pests (e.g. the wasp Dolichogenidea metesae [Basri, et al., 1995; Corley and Tinker, 2003]).

Box 5: Land Use Planning as a Means of Enhancing the Sustainability of Biofuel Plantations

Other means of mitigating the impacts on biodiversity loss within the oil palm plantation landscape include the formation of riparian buffer zones to reduce water pollution, preservation of high conservation value (HCV) forests, formation of wildlife buffer zones to 'soften' the edge between plantations and natural forests and the creation of habitat corridors to link remnant forest patches together (Maddox, 2007; Fitzherbert, et al., 2008).

6.3 Designer Landscapes

Addressing the problems arising from indirect land use changes require a landscape-level approach where biofuel feedstock production has to be coordinated within the industry and with regional or national land-use plans (Maddox, 2007; Koh, et al., 2009b). From an ecological perspective, two concepts have been proposed to minimise the adverse impacts of agricultural expansion on biodiversity: land sparing and wildlife-friendly farming. The former seeks to minimise land area required for farming by land intensification through maximising yields and the latter tries to enhance biodiversity within an agricultural landscape (Fischer, et al., 2008). Koh, et al. (2009) proposed a harmonisation of both approaches to design landscapes threatened by biofuel expansion based on optimal requirements for sustaining biodiversity, economic, and livelihood needs. Agroforestry (wildlife-friendly farming) zones around high conservation value (HCV) areas can be used as corridors to connect surrounding fragments of HCV forests, act as buffer zones to mitigate human encroachment into HCVs, and reduce edge and matrix effects from the intensively cultivated biofuel feedstock landscape (land sparing). How effective such an approach would be has yet to be tested in the field but offers a possibility for a more sustainable pathway for future biofuel expansions. Engagement with local stakeholders and support from local authorities are particularly important in developing nations such as Brazil and Indonesia where rural development and improvement of people's well-being are urgent priorities.

6.4 PES and REDD

Biofuels is only one of many financially valuable uses of land. Apart from their biodiversity values, it is imperative to recognise that ecosystem services and natural habitats provide including genetic diversity, carbon sequestration, water cycling and purification, climate regulation, and many other non-timber products which are not found elsewhere (Costanza, et al., 1997).

Innovative schemes such as Payment for Ecosystem Services (PES) or Reducing Emissions from Deforestation and Degradation (REDD) create financial incentives to divert biofuel feedstock expansion away from forests and onto pre-existing croplands or degraded lands. The establishment and enforcement of protected areas is a legislative tool that remains a top strategic priority for protecting biodiversity. PES and REDD can be used to both protect biodiversity and mitigate other negative effects of biofuels on ecosystem services (e.g. water provision and climate regulation).

The question which follows then is whether such incentives are sufficient to counter strong market forces that favour natural habitat conversion. Recent REDD scheme partnerships between non-governmental organisations and private companies (Fischer, 2009) are positive steps towards greater collaboration and engagement of various stakeholders towards conserving tropical forests. However, few studies have compared the feasibility of such schemes against current market prices for biofuel feedstocks. Butler, et al. (2009) compared the profitability of converting forests into oil palm plantations against conserving forests for a REDD scheme. Under current voluntary carbon markets, conversion of forest into oil palm (yielding net present values of 3835 to 9630 USD per hectare over a 30 year period) will be more profitable to landowners than preserving it for carbon credits (614 to 994 USD). However, should REDD become a legitimate emissions reduction activity under the second commitment period of the Kyoto Protocol (2013-17), carbon credits traded in Kyoto-compliance markets have a fighting chance to compete with oil palm agriculture or other similarly profitable human activity as an economically attractive land-use option. Similar economic evaluations of comparing the value of non-forest biodiverse habitats like the Cerrado to soybean and sugar cane production in Brazil can also be carried out to determine the competition of various land uses based on monetary values.

A recent study by Igari, et al. (2009) calculated an annual profitability of 134 USD/ha/year and 149 USD/ha/year for sugar cane and soybean crop respectively growing near the Cerrado region in São Paulo State, Brazil. Opportunity costs to set aside the Cerrado for preservation were much higher compared to PES values of 27 USD and 42 USD per ha paid to landowners in Mexico and Costa Rica respectively (Muñoz-Pina, et al., 2008; Barton, et al., 2009) and only slightly comparable (111 USD per ha) to the average annual value paid by USDA Conservation Reserve Programme in the United States (USDA, 2006; Baylis, et al., 2008).

Considerable amount of research is currently underway to use REDD as a tool against natural habitat conversion by other human land use activities (Butler, et al., 2009). However, for natural habitats, which are already slated for land use conversion, complete avoidance is not a realistic option and strategies to mitigate biodiversity impacts will have to be formulated. There is also the risk that financial lure of REDD might inadvertently cause some landowners to accelerate habitat destruction to raise the deforestation baseline of future REDD projects so that they might reap more monetary benefits (Koh, et al., 2009a; Koh, 2009). Furthermore, some researchers warn that the indirect and less tangible environmental and socio-economic implications of PES schemes need to be carefully evaluated (Ghazoul, et al., 2010a, b). Some of these wider societal costs of withholding development might include the forfeiture of employment opportunities and tax revenues.

6.5 Certification Schemes

To ensure that biofuel and biofuel feedstock producers are encouraged to adopt sustainable practices, international certification schemes which satisfy a set of social and environmental criteria have been introduced. Creation of multi-stakeholder organisations such as the Roundtable of Sustainable Biofuels (RSB), the Roundtable of Responsible Soy (RTRS), the Better Sugar cane Initiative (BSI), and the Roundtable of Sustainable Palm Oil (RSPO) aim to engage a diverse range of stakeholders in the biofuel sector – governments, non-governmental organisations, producers, consumers, suppliers – to work towards producing biofuel feedstocks using sustainable practices (Laurance, et al., 2010). These organisations create, verify, and certify performance standards for sustainable production of biofuel feedstocks and biofuels (UNEP, 2009).

Through these organisations, conservation groups have a platform to engage and inform producers of suitable new areas for biofuel expansion which will lead to the least ecological damage. Independent Environmental Impact Assessments (EIAs) of future biofuel crop plantings and Life Cycle Analyses (LCAs) of biofuel products provide greater transparency on the costs of biofuel production and reassure consumers that biofuels purchased are produced with the best sustainable practices (UNEP, 2009). However, critics of biofuel certification schemes argue that market-based product certification often cover only a fraction of the market size (Sto, et al., 2005; Liu, et al., 2004; Laurance, et al., 2010) and may be misleading as some production appear to be sustainable but in fact are not (Doornbosch and Steenblik, 2007; Laurance, et al., 2010). Most importantly, it has no control over the extent of indirect land use change resulting from displacement of other land use activities by biofuel production (Doornbosch and Steenblik, 2007).

7. Concluding Remarks

This report has provided an analysis of the drivers and impacts of biofuel production on ecosystem services and biodiversity. The ecosystem services approach (MA, 2005) has been used to frame the analysis. This approach (1) enables to link biofuels' ecosystem impact on human well-being by highlighting the associated trade-offs between ecosystem services and their respective social benefits and costs, and (2) is broadly recognised among academics, conservation practitioners, and policy-makers, hence facilitating communication regarding both the design and the implementation of adequate policies aiming for sustainable biofuels. The review has addressed liquid biofuels (e.g. bioethanol and biodiesel) and has focused on first generation biofuels, since these currently provide the bulk of the biofuel supplied worldwide and is projected to continue to increase at least until 2019 (OECD-FAO, 2010).

While the negative impacts of biofuel production/use have attracted most of the attention in this review, there are also several studies that have been cited and show how biofuel production can have positive impacts. This suggests that biofuels cannot be grouped together since they encompass vastly different production practices that take place in different ecosystems, to achieve different goals, and compete with multiple human activities.

Biofuel production and use can, during its whole life cycle, affect several ecosystem services negatively or positively. The main ecosystem services affected are: provisioning services (e.g. fuel, food, freshwater), regulating services (e.g. climate regulation, air quality regulation, erosion regulation), and cultural services.

Fuel: Biofuels have been proposed as alternative transport fuels. However, the overreliance on fertilisers and agrochemicals for feedstock production cast doubt on their potential in the long term. In spite of this, several biofuels are net energy suppliers and as a result can contribute positively to energy security in the short-to-medium term.

Food: Production of biofuels can compete directly and indirectly with food production. A manifestation of this competition has been the food price increases of the past few years. This competition is expected to intensify in the future.

Freshwater: Biofuel production can deplete and degrade water bodies. Biofuels exhibit higher water footprints than fossil fuels and other renewable energy sources. At the same time, fertilisers, agrochemicals, and effluent from biofuel refineries can degrade water bodies. However, with adequate management practices, biofuel feedstock production can contribute to environmentally friendly water sewage treatment and as a means for improving water quality in aquifers.

Climate regulation: Studies have shown that biofuels generally emit less GHG in their full life cycle than fossil fuels. However, such studies usually disregard the impact of direct and indirect land use change on GHG emission. Biofuels grown on former agricultural land seem to result in smaller carbon debts.

Air quality regulation: Several air pollutants can be emitted during biofuel production and use. The emission of these pollutants depends on the agricultural practices used (e.g. fertiliser use, land clearing through burning, etc) and the combustion technology, among others.

Erosion regulation: The extensive cultivation of major biofuel feedstocks such as sugar cane, soybeans, and oil palm are major causes of soil erosion. However, other feedstocks such as jatropha can improve soil quality and control erosion in marginal lands.

Cultural services: Currently, there is a lack of studies exploring the linkage between biofuel production and cultural services. However, biofuels are usually grown in extensive monoculture systems that have been proven to affect cultural ecosystem services negatively.

The analysis found that biofuel production also affects biodiversity. Special drivers are habitat destruction, interaction with other frontier opening activities, invasive alien species, and pollution.

Habitat destruction: This is considered as perhaps the most important threat to biodiversity. Conversion of natural habitats into monocultures implies a drastic loss in biodiversity and change in the composition of species communities in the area. Biodiversity in the tropical regions of South East Asia and Latin America is under the greatest threat from biofuel expansion, and particularly from oil palm, sugar cane, and soybean expansion. However, as compared to intensive agriculture, carefully planned small-scale biofuel production could potentially support biodiversity.

Interaction with other frontier opening activities: The development of biofuel plantations is associated with industrial activities like logging, cattle ranching, and the building of roads and waterways. Together, they are indirect drivers of habitat loss and degradation, by increasing the accessibility of natural resources for further exploitation and raising the level of fragmentation and isolation of remnant natural habitats.

Pollution and invasive alien species: Poor production practices of biofuel feedstock have been noted for oil palm, sugar cane, and soybean. Examples include intensive use of fertilisers and pesticides, the use of fire for land clearing, soil degradation, water and air pollution, which in turn could lead to long-term ecological impacts in the tropics. Moreover, there are fears that biofuel feedstocks such as perennial grasses and jatropha might become invasive.

Several possible response options are described in this report. At the core of the interventions lies the opportunity cost of land (land used for e.g. fuel, food, fodder, or forests). The choice of production technology (e.g. high yielding feedstocks) and location (marginal land) can contribute to the sustainability of feedstock production. In other cases, land management measures such as conservation corridors can significantly reduce the negative effects on ecosystems. Innovative incentive schemes such as payments for ecosystem services for water provision and carbon sequestration have already been implemented in other areas and should be explored further.

However, markets and decentralised action alone are not sufficient to make explicit and communicate to consumers the many values of ecosystems in such a way that consumption choices become sustainable. For example, the fact that biofuels are often sourced from faraway production sites can distort the information for buyers trying to make sustainable consumption choices. In this context, concerted action is needed to establish, communicate, and implement minimum standards. For all response options, the ecosystem services concept can be a powerful aid for assessing the sustainability of biofuels, and to help develop and communicate appropriate biofuel standards.

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UNU-IAS Policy Report

Impacts of Liquid Biofuels on Ecosystem Services and Biodiversity

Per M. Stromberg, Alexandros Gasparatos, Janice S.H. Lee, John Garcia-Ulloa, Lian Pin Koh and Kazuhiko Takeuchi

Ecosystem services are benefits people obtain from ecosystems. In this report, the ecosystem services concept is used to rationalise the existing evidence about biofuels' impact on ecosystems. It is shown that biofuels can provide a number of ecosystem services (e.g. fuel, climate regulation) while compromising others (e.g. food, freshwater services). At the same time, it is also shown why biofuel expansion is currently being considered as one of the main emerging threats to biodiversity, particularly in highly biodiverse areas such as in Indonesia and Brazil. A combination of response options such as designer landscapes, Payment for Ecosystem Services (PES), Reduction of Emissions from Deforestation and Degradation (REDD), and biofuel certification will have to be put in place to minimise the negative impacts of biofuel expansion on ecosystem services and biodiversity.

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