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Analysis of the Viability of Ethanol Production in Brazil: Economical, Social & Environmental Implications

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Abstract

The global dependency on fossil fuels as energy sources has encouraged many countries to look for different renewable alternatives. Some have come to consider biofuel production as the 'solution' to the oil dependency. The leaders of ethanol production in the world are the United States and Brazil. This paper will focus on ethanol production in Brazil, outlining its development through Brazil's history as well as the advantages and the negative impacts of such a market. The importance of this energy source in Brazil's economy and the possible future outcomes of Brazil's biofuel dependency will be discussed. Three different aspects of primary impacts will be highlighted: economic, environmental and social. The effects of the new advancements in emerging biofuels will be discussed as they pertain to the current market for first-generation biofuels. An analysis of the economic impacts of ethanol will concentrate on the influence of the American ethanol market and its policies on Brazil. The environmental impacts of land use change, with a focus on soil, water and biodiversity, will also be reviewed. Likewise, the social impacts associated with food security, sugarcane workers and indigenous peoples' rights will be discussed. An overall view of the repercussions of biofuel production will be presented and questions regarding the viability of the biofuel market in Brazil will be addressed.

Keywords: Brazil, biofuel, sugarcane, ethanol, energy

1. Introduction

1.1 Overview of Global Energy Production

Global energy consumption has increased significantly over the past decades. Most of the energy resources consumed are non-renewable in nature (e.g., crude oil, natural gas and coal). According to the British Petroleum Statistical Review of World Energy (2012), global energy consumption grew by 2.5% in 2011, which coincided with 1.1 million barrels per day (0.175×10^9 L d^{-1}) increase in oil production. Oil accounts for approximately a third of global energy consumption (British Petroleum [BP], 2012). Increasing difficulty in satisfying world energy demands and a dependency on scarce fossil fuels has pressed the global community to find new renewable alternatives. Renewable resources which are currently available include: solar energy, hydroelectricity, tidal power, wave power, wind power and biofuels. In principle, biofuel production technologies have been developed to reduce transportation vehicles' emissions of greenhouse gases into the atmosphere. During the past decades, there has been an increasing interest in the development of the biofuel sector. Brazil became a leader in biofuel exports in 2007, having a 32% share of global ethanol production (BP, 2012). Global bio-ethanol production tripled between 2000 and 2007, with the US and Brazil accounting for the majority of this growth (BP, 2012). While other forms of renewable energy (e.g., solar and wind energy) increased significantly, global biofuel production grew by only 0.7% in 2011, the lowest annual rise since 2000 (BP, 2012). This paper discusses more specifically the impact of ethanol production in Brazil in environmental, social and economic contexts.

1.2 What Are Biofuels?

1.2.1 First-Generation Biofuels

First-generation biofuels have been produced from starch-, sugar- or oil-bearing food crops, as well as animal fat feedstock (Biofuel.org.uk, 2010a). The primary source for ethanol production worldwide is corn (*Zea mays L.*). In the United States roughly 40% of the corn crop is used in ethanol production. Some of the advantages of corn

grain as a feedstock include its fairly easy conversion from starch to ethanol, and the promise that the remainder of the plant can also serve in ethanol production. However, using corn as feedstock has adverse environment effects since it requires enormous amounts of fertilizer and pesticide inputs, which can undermine soil and water quality. Also, the ethanol production rate is relatively low with an average of 3.27×10^3 L ha^{-1}, with a net energy yield of only 20%. According to Biofuel.org.uk (2010a) corn cannot be considered a viable fuel feedstock given its primary importance in the food chain.

Sugarcane (*Saccharum officinarum L.* × *Saccharum spontaneum L.*) provides sugar rather than starch. It is more easily converted to alcohol since the process only requires fermentation, rather than both heating and fermentation in the case of starch. The production yield of sugarcane is higher than corn at an average of 6.08×10^3 L ha^{-1}. Interestingly, carbon dioxide emissions can be 90% lower compared to emissions from gasoline when land use changes do not take place. Nonetheless, this crop has a relatively low yield and in places such as South and Central America, sugarcane is a food staple. Sugarcane is unlikely to resolve global energy needs since it cannot be scaled to non-tropical nations.

Soybean [*Glycine max* (*L.*) Merr.] is used to produce biodiesel, but is usually considered the worst feedstock since it usually requires more energy to cultivate soybeans than the energy output they provide. Also, given its importance as food source, it's use as a biofuel feedstock represents a threat to the food chain (Biofuel.org.uk, 2010a).

1.2.2 Second-Generation Biofuels

Second-generation biofuel production uses feedstocks that are not suitable for human consumption and can be grown on marginal lands, with little water or fertilizer (Biofuel.org.uk, 2010b). Due to different processes preparatory to fermentation, the extraction technology for these biofuels differs from that of the previous generation's feedstocks. These processes are divided into thermo-chemical and biochemical conversion. The most common feedstock crops used in second-generation biofuel production are grasses, jatropha (*Jatropha curcas L.*), waste vegetable oil and municipal solid waste. Grasses such as switchgrass (Panicum virgatum L.), Miscanthus (*Miscanthus* × *giganteus* J. M. Greef, Deuter ex Hodk., Renvoize), Indiangrass [*Sorghastrum nutans* (*L.*) Nash] and others have been used in many different regions according to climate suitability. The main advantages of these feedstocks include: relatively low fertilizer needs, their ability to grow on marginal land, the possibility of using them directly as biomass, and the high net energy yield to energy input ratio of 5.4. However, grasses are not suitable for biodiesel production and they entail extensive processing to be converted into ethanol. Moreover, the time for switch grass to attain harvest density can be lengthy and grasses do not do well in arid climates since they require significant soil moisture to grow. Indeed, the biggest disadvantage of using grasses as feedstock is their high water demand for growth (Biofuel.org.uk, 2010b).

Ultimately, the production of second-generation biofuels is considered more sustainable than some first-generation biofuels due to their potential production on marginal lands. However, full commercialization of biochemical or thermo-chemical conversion for second-generation biofuel production appears to be some years off (Sims et al., 2010). According to Sims et al. (2010), unless there is a technical breakthrough in the conversion route, the successful commercialization of second-generation biofuels may possibly take another decade.

1.2.3 Third-Generation Biofuels

Third generation biofuels refers to biofuels derived from algae. Algae are capable of significantly higher yields with lower resource inputs than any other feedstock (Biofuel.org.uk, 2010c). More importantly, algae can produce oil that can be easily refined into diesel or even certain components of gasoline. Also, algae can be genetically manipulated to directly produce fuels ranging from ethanol and butanol to even gasoline and diesel fuel. Fuels that can be derived from algae include: biodiesel, butanol, gasoline, methane, ethanol, vegetable oil and jet fuel. Butanol is of great interest since it is similar in properties (e.g., density) to gasoline, but has an improved emissions profile. At present, several commercial-scale butanol production facilities have been developed, making it a more popular biofuel than ethanol. Furthermore, algae are capable of producing greater yields than other biofuels, with some algae having been shown the ability to produce up to 84.18×10^3 L ha^{-1} a 10-fold improvement over the best traditional feedstock. Another property of algae is that it can be cultivated in many different ways: (i) open ponds offer the lowest capital costs but are less efficient, (ii) closed-loop systems use a sterile source of carbon dioxide, and (iii) photo-bioreactors are the most advanced, but require complex implementation systems thus resulting in high capital cost. Algae are capable of growing anywhere where temperatures are sufficiently high and as an added advantage they can even grow in wastewater, providing secondary benefits such as the digestion of municipal waste.

Moreover, since algae have the added ability to use several different carbon sources it has been suggested that

algae should be coupled to major carbon emitting sources, where they can directly convert these emissions into fuel. This would result in a major decrease of total carbon emissions. The major disadvantage of algae is that they require significant amounts of water and nutrients to grow. Therefore it is possible that the quantity of fertilizer required to produce algae-based biofuel on a large scale would lead to greater greenhouse gas emissions than the resultant biofuel would have saved (Biofuel.org.uk, 2010c).

More importantly, the aim of developing this generation of biofuels is to design crops that allow improved bioconversion and higher yields. Advancement in plant biology has improved crop yields through such methods as molecular breeding, genomics, and transgenic crops (Biopact, 2007). These recent innovations have allowed for the development of crops more suitable for conversion into bioproducts. For instance, scientists have developed eucalyptus (*Eucalyptus obliqua L'Hér*) trees with a low lignin content that permits an easier conversion into cellulosic ethanol. Also, scientists at Texas A&M University's Agricultural Experiment Station have been able to increase biomass yield of crops such as sorghum [*Sorghum bicolor* (*L.*) Moench] and they are now breeding drought tolerant sorghum (Biopact, 2007).

1.2.4 Fourth-Generation Biofuels

This generation represents the latest advancement in the biofuel field since the energy crops used as feedstock are designed to improve carbon storage and produce higher yields (Biopact, 2007). Fourth-generation biofuels are described as carbon-negative given that biomass crops can take carbon dioxide from the atmosphere and store it in leaves, branches and trunks. The bioconversion process follows fermentation, gasification and fast-pyrolysis. The carbon dioxide that is released before, during or after these processes is captured using pre-combustion, oxyfuel or post-combustion processes. Then this greenhouse gas is accumulated in depleted oil and gas fields or saline aquifers where it stays locked away for many years. The bio-energy with carbon storage (BECS) systems serves to take carbon dioxide from the atmosphere while providing clean energy. For this reason these systems are seen as "the only low-risk geo-engineering methods" that can help to deal with climate change. New developments in "carbon capture and storage" technologies could be applied to biomass where the carbon-negative fuel would be produced locally and then transported to end-users. The U.S. Department of Energy's National Energy Technology Laboratory (DOE/NETL) and the U.S. Air Force (USAF) are taking the first steps towards these new developments; they have released a report on "production of fuels made from combining the liquefaction of both coal and biomass, and then coupling the system to carbon sequestration technologies" (Biopact, 2007).

Synthetic Genomics (SGI) is presently at work facilitating the production of algal fuels in large-scale industrial operations by modifying algal cells to continuously produce and secrete oil through their cell walls (Synthetic Genomics, 2012). Also, SGI is working in collaboration with ExxonMobil Research and Engineering Company (EMRE) to investigate the most efficient and cost-effective techniques to manufacture the next generation of biofuels by using photosynthetic algae. The company aims to "discover and develop superior strains of algae using leading edge genomic technologies" (Synthetic Genomics, 2012).

Fourth-generation biofuels therefore offer a promising future for the fuel industry and offer a possible solution to climate change.

1.3 What Is Ethanol?

Ethanol is an alcohol obtained through fermentation of feedstock bearing high levels of sugar or starch (GreenFacts, 2012b). Sugar can be directly converted into alcohol, but starch must first be converted into sugar (GreenFacts, 2012b). Therefore, the simplest way to produce ethanol is by using sugar crops. Ethanol is used in the transportation sector mainly because it improves the vehicular fuel combustion, thus reducing carbon monoxide emissions (Food and Agriculture Organization [FAO], 2008). Another advantage of ethanol is that when it is mixed with gasoline, it reduces the fuel's sulphur content, thereby reducing sulphur emissions, a component of acid rain and a carcinogen (FAO, 2008). The biomass productivity of sugar cane can reach up to 80-120 Mg ha^{-1} yr^{-1} with an industrial ethanol production of 8,000 L ha^{-1}, well exceeding the 3,000 L ha^{-1} that can be produced from maize (Basso et al., 2011). Both sugar cane and maize have shown the presence of nitrogen-fixing endophytic bacteria. Moreover, it has been proposed that at least "60% of the plant's nitrogen requirement, is supplied endogenously when sugar cane is grown in low fertility soils" (Basso et al., 2011). Given that sugar cane requires less fertilizer inputs than maize and nitrogen fertilizers are costly and require large amounts of fossil energy to produce, the use of sugar cane as a feedstock presents significant economic and environmental benefits over corn. The major portion of the energy spent in sugarcane-based ethanol production arises from agronomic needs (e.g., fertilizers and transportation; Basso et al., 2011).

1.4 Brazil & Ethanol Production

1.4.1 Past Production

Brazilian bio-ethanol production began in the 1930's (Ross, 2012). During the Arab oil embargo of 1973 and the resulting global oil crisis, Brazil was severely affected as its oil imports costs tripled (Basso et al., 2011). The 1974 decline in world sugar prices led Brazil to launch the Brazilian National Alcohol Program (PROALCOOL) the next year (Basso et al., 2011). This program sought to achieve large-scale ethanol production and adapt engines to burn a 1:4 ethanol:gasoline mix named E20 (Basso et al., 2011). International and first world nations' concerns regarding fossil fuel consumption-driven global warming and greenhouse gas emissions in 2007, led the biofuel industry to emerge as the new alternative. Brazil and other tropical countries became producers of agro-energy given the low labour costs and favourable conditions for biofuel feedstock production prevailing there (Sawyer, 2008). Since then, in order to reduce its dependence on oil, Brazil has significantly increased its bio-ethanol production. The main advantages of investing in biofuel production in Brazil include the reduction of greenhouse gas emissions, a lesser dependence on fossil fuels, job creation along with income and foreign investment opportunities (Sawyer, 2008). The expansion of the biofuel market depends on government subsidies, as production costs of biofuel are sometimes higher than those of fossil fuels (Hoogeveen et al., 2009). However, in Brazil, sugarcane is competitive with gasoline "at a crude oil price of around US$35 per barrel, whereas, crude oil prices were over US$140 per barrel at the end of June 2008". (Hoogeveen et al., 2009).

1.4.2 Current Production

The largest producers of ethanol in 2007 were Brazil and the United States, accounting for 90% of the total global production of ethanol (FAO, 2008). Statistics of ethanol and biodiesel production in Brazil, the United States and a number of other countries (Table 1) shows these two countries to indeed be the global leaders in ethanol production. Additionally, "global bio-ethanol production is expected to reach more than 125 billion litres in 2017, twice the quantity produced in 2007" (Hoogeveen et al., 2009).

Table 1. Top 25 countries, ethanol production capacity (Global Biofuels Centre, 2010)

Rank	Country	Million Liters	Million Gallons
1	United States	51,415.97	13,584.14
2	Brazil	26,887.52	7,103.70
3	China	2,699.48	713.20
4	France	1,821.03	481.12
5	Canada	1,494.50	394.85
6	India	1,420.92	375.41
7	Poland	1,079.00	285.07
8	Germany	916.97	242.26
9	Thailand	868.50	229.46
10	Jamaica	832.70	220.00
11	T & T	757.00	200.00
12	Indonesia	683.38	180.55
13	Spain	546.00	144.25
14	Austria	485.00	128.14
15	Belgium	485.00	128.14
16	Netherlands	480.00	126.82
17	United Kingdom	470.00	124.17
18	US Virgin Islands	387.50	102.38
19	Colombia	352.00	93.00
20	Vietnam	318.11	84.04
21	Australia	292.70	77.33
22	Czech Republic	280.00	73.98
23	El Salvador	247.10	65.28
24	Paraguay	237.25	62.68
25	Argentina	237.20	62.67
	Total	95,694.83	25,282.65

Source: Global Biofuels Center

Ethanol is the main biofuel used in the transportation sector in Brazil and the country is positioned as the second major bioethanol producer and the greatest exporter (Basso et al., 2011). In Brazil, the sugar and ethanol industry represent 2.3% of the Gross Domestic Product and generate 4.5 million jobs (Basso et al., 2011). Moreover, "fuel ethanol represents almost 50% of the total fuel volume consumed by cars" (Basso et al., 2011). Brazil's ethanol production uses sugarcane as its primarily feedstock. Currently, sugarcane occupies 8×10^6 ha with a production of more than 0.6 Pg yr^{-1}, making Brazil the world's largest sugar cane producer (Basso et al., 2011).

1.4.3 Agricultural Expansion

With the latest expansion of bio-energy in developed and developing countries, the role of agriculture has become essential in these energy markets. This unprecedented new demand for farmer's products represents a promise for an increase in employment in the agricultural sector; however, using food crops as feedstock for ethanol increases the competition for natural resources such as land and water (GreenFacts, 2012b). This competition for resources becomes an issue mostly because some of the crops that are being cultivated for food are redirected towards biofuel production and some agricultural lands traditionally used for food production have been converted to biofuel production (FAO, 2008). This is the case in the United States, where corn is both used in the food market and in the biofuel market. Moreover, critical factors in the production of biofuel in the agricultural sector include the use of fertilizers, pesticides, irrigation, soil treatment, water use and the impact of land-use changes, such as cutting down forests for agricultural purposes (FAO, 2008).

2. Repercussions

2.1 Economical Impacts

According to British Petroleum records from the year 2012, Brazil's ethanol output showed its greatest decline since 1965 [-15.3%]. This was the result of a poor sugarcane harvest in the face of renewable energies that have shown continued growth during the same period of time (BP, 2012). Having to depend on optimal environmental conditions for sugarcane growth represents a risk to the economy, since any source of natural or anthropogenic disturbance can affect not only ethanol production but many sectors in the economy that depend on the biofuel market income. By 2015, more biofuel production is expected to use cellulose as an input, rather than food crops (Sawyer, 2008). This type of process would most probably be conducted in developed countries since high-tech industrial processing of generic plant biomass would be required (Sawyer, 2008).

Moreover, global ethanol production is expected to reach 180×10^9 L yr^{-1} by 2021, almost twice the production of 2009-2011 (Food and Agriculture Organization [FAO], 2012). Three major producers will take the lead in this rise in production: the United States, Brazil and the European Union. In the United States and the European Union, ethanol production and use is driven principally by policies already in place [*e.g.*, US Renewable Fuel Standard (RFS2) final rule and the EU Renewable Energy Directive (RED), respectively]. As for Brazil, the emergent use of ethanol is influenced by the expansion of the flex-fuel vehicle industry and the import demand of the United States to achieve the advanced biofuel mandate. Only fuels that reach a 50% greenhouse gas reduction score are considered in the advanced biofuel mandate. Ethanol derived from sugar is explicitly defined as an advanced fuel. The overall mandate requires fuels to attain at least 20% greenhouse gas reduction by 2021. Brazil is then expected to become the world's second largest ethanol producer, with production rates reaching 51×10^9 L yr^{-1}. This will represent 28% of global ethanol production in the target year of 2021. Domestic use of ethanol in Brazil is expected to reach 40×10^9 L yr^{-1} in 2021. This growth will be primarily due to a growing fleet of flexi-fuel vehicles (FAO, 2012).

The main uncertainties about first generation biofuels is the possibility of their future replacement by advanced biofuels produced from lignocellulosic biomass, waste material and other non-food feedstock (FAO, 2012). This transition will depend on the profitability expectations shaping industry investment choices and private research and development efforts as well as on the nation's biofuel policy framework. Policies put in place will determine public spending and provide guidelines for the private sector. The policies developed in the United States by the Environmental Protection Agency (EPA) will affect the ethanol market on a global scale, including competitors such as Brazil. The FAO estimates that by 2021 the decisions made by the EPA will have large impacts on agricultural markets. Three alternative implementation options exist: (i) lowering the total and advanced mandates by the shortfall in the cellulosic mandate, (ii) maintaining both the advance and total mandates, or (iii) maintaining the total mandate and lower the advanced mandate by the shortfall in cellulosic production. The EPA has chosen the second option, which could have a major influence in Brazilian ethanol and sugar markets, ethanol use and ethanol imports from the United States. Brazil's ethanol market is the only one capable of large-scale production from sugarcane, and the country is the only one with the capacity and flexibility to respond to additional demand from foreign markets. The baseline projection assumes that cellulosic ethanol

production will increase gradually over the period of 2011-2021 to reach 16×10^9 L yr^{-1}, which is only 30% of the cellulosic biofuel mandate. Firstly, an increase in ethanol production will require an expansion of 9% in sugarcane acreage compared to baseline, and a greater proportion of sugarcane being used for biofuel than sugar production. Lower sugar production will likely entail higher domestic sugar prices, a lesser sugar demand and an important decrease in sugar exports. Consequently, global sugar prices are predicted to increase by 6% in 2021 compared to baseline levels. Secondly, Brazilian ethanol demand is supposed to decrease significantly. This will lead to reductions in minimum blending requirements and ethanol use by flex-fuel vehicles to 21% of the total fuel consumption. Thirdly, to meet domestic demand in a situation of a notable increase in Brazilian ethanol exports, the country will need to increase imports. These imports are expected to reach 18×10^9 L yr^{-1}, which will mainly originate from the United States (FAO, 2012). Brazil's dependency on foreign policies will create a source of economic vulnerability given the United States' policies' significant influence on Brazil's ethanol and sugar markets. Moreover, extending areas of sugarcane production will undoubtedly provoke environmental impact and related land tenure and social issues, which will be further discussed below.

2.2 Environmental Impacts

2.2.1 Greenhouse Gas Emissions

Biofuels have been developed as an alternative source of energy to fossil fuels. As mentioned before, the promotion of biofuels has come from a desire to reduce greenhouse gas emissions. In this sense, a comparative energy analysis of biofuels versus fossil fuels needs to include the total energy required throughout the whole cycle of the biofuel production process (cultivation, harvesting, processing, transportation, production and distribution) (FAO, 2008). Indeed, the fact that the fertilization required in sugarcane production can lead to the soil-mediated release of potent GHGs [e.g. nitrous oxide (NO_2) and methane (CH_4)] must be taken into account (Ross, 2012). Moreover, the deforestation arising from land-use shifts towards agriculture contributes to 75% of Brazil's CO_2 emissions as well as decreases the disturbed ecosystems' ability to convert the greenhouse gas CO_2 back into oxygen (Ross, 2012). In fact, Brazil contributes to 3% of global greenhouse gas emissions, ranking fourth globally in this regard (Ross, 2012). The production of biofuel is not totally independent from fossil fuels. Fossil fuels are still required for fertilizer production, transportation of inputs and labour, manufacture and operation of farm machinery, processing of raw material and the transportation of crops to markets (Sawyer, 2008). Considering all these facts, the production of biofuels can hardly be said to be 'carbon neutral'.

Another effect to consider is that the expansion of sugarcane into cattle farms has created pressure towards further deforestation. Although some legislation exists disallowing the planting of soya and sugarcane in the Amazon, there are no restrictions on purchasing land to raise cattle (Sawyer, 2008). Thus, ranchers who sell their already forested land can then afford to purchase an almost ten-fold greater area of forest for cattle-raising purposes (Sawyer, 2008). This not only exacerbates deforestation and its subsequent environmental effects, but also increases CH_4 emissions from cattle.

2.2.2 Water Requirements and Water Pollution

Due to the climatic conditions prevalent in Brazil, most sugarcane is grown under rainfed conditions (Hoogeveen et al., 2009). Though water requirements, and by extensions irrigation water withdrawals, may vary depending on agro-climatological conditions and irrigation efficiencies, typical requirements for Brazilian sugarcane destined for bio-ethanol production were calculated assuming a 50% overall irrigation efficiency (Table 2; Hoogeveen et al., 2009). This calculation showed that under conditions prevalent in Brazil it takes 2000 L of water to produce 1 L of biofuel from sugarcane (Table 2). This should raise concerns in regions such as the northeast of Brazil where agriculture is supported through irrigation, rather than being rainfed (Hoogeveen et al., 2009) since in these areas the stress on water resources will be greater.

Deforestation practices to create land for monocultures can affect the quality of water and increase soil erosion due to the removal of vegetation (Sawyer, 2008). There is an obvious relationship between the expanse of sugarcane plantations and water pollution since the fertilizers and pesticides used contain nitrogen and phosphorous which are the main contaminants of water, soil and aquifers (Ross, 2012). An example of this is the Ipojuca River, which has been severely affected by "nitrate leaching and acidification, [resulting in] increased turbidity and oxygen imbalance" (Ross, 2012). When these contaminants reach the waterways they become a threat for aquatic environments and drinking water resources. Brazilian authorities have passed legislation to protect water from pollution associated with sugarcane production (Ross, 2012), but having such a large area of sugar plantations has made it difficult to enforce this legislation.

Table 2. Indicative yields and water requirements for some major biofuel crops (Hoogeveen et al., 2009)

Crop	Fuel product	Annual obtainable yield ($l\,ha^{-1}$)	Energy yield ($GJ\,ha^{-1}$)	Potential crop evaporation in mm (indicative)	Evaporation (litre $litre^{-1}$ fuel)	Irrigated or rainfed Production	Rainfed conditions	Water resource implications under irrigated conditions (assuming an irrigation efficiency of 50%)	
							Actual rainfed crop evaporation (in mm, indicative)	Irrigation water used (in mm, indicative)	Irrigation water used (in litre $litre^{-1}$ fuel, indicative)
Sugar cane	Ethanol (from sugar)	6 000	120	1 400	2 000	Irrigated/rainfed	1 100	600	1 000
Sugar beet	Ethanol (from sugar	7 000	140	650	786	Irrigated/rainfed	450	400	571
Cassava	Ethanol (from starch)	4 000	80	1 000	2 250	Rainfed	900	—	—
Maize	Ethanol (from starch)	3500	70	550	1 360	Irrigated/rainfed	400	300	857
Winter wheat	Ethanol (from starch)	2 000	40	300	1 500	Rainfed	300	—	—
Oil palm	Biodiesel	6 000	193	1 500	2 360	Rainfed	1 300	—	—
Rapeseed/ mustard	Biodiesel	1 200	42	500	3 330	Rainfed	400	—	—
Soybean	Biodiesel	450	14	500	10 000	Rainfed	400	—	—

Source: adapted from Müller *et al.* (2008).

2.2.3 Climate Change and Biodiversity

The Cerrado, located in the central region of Brazil, is the world's most diverse savannah (Ross, 2012). This region's favourable topography as well as its abundance in water resources has made this region the Brazilian government's choice for the expansion of sugarcane plantations (Ross, 2012). Currently there is two-to-three times as much annual deforestation in the Cerrado 0.22-0.3 $\times$ 10^6 km^2, compared with 0.131 $\times$ 10^6 km^2 in 2005-2006. In fact 0.8-1.6 $\times$ 10^6 km^2 of the Cerrado region has been deforested, compared to 0.7 $\times$ 10^6 km^2 in the Amazon (Sawyer, 2008). According to various climate change scenarios, clearing the Cerrado can have severe repercussions on global biodiversity since it would receive less water from the Amazon (Sawyer, 2008). The Cerrado region, being composed of woodlands and savannah, is rendered vulnerable because it considered to be of low value and is therefore less protected. However, it is in fact home to a great deal of biodiversity (Sawyer, 2008). Shifting rainfall patterns and increasing evaporation rates associated with higher temperatures will put some areas where forests have been cleared at risk of desertification. This is an essential issue that should be evaluated when assessing the sustainability of future biofuel production.

2.3 Social Impacts

2.3.1 Land Tenure and Workers

Since monocultures need vast areas to grow, the socio-economic impacts of biofuel production are largely related to the increasing concentration of land tenure. For example, the expulsion of small farmers from their lands by large-scale ethanol producers in the 1970s and 1980's led to particularly acute land tenure conflicts (Ross, 2012).

Moreover, the most vulnerable people (e.g. indigenous communities) are those who are most severely affected.

Indeed, the Chair of the UN Permanent Forum on Indigenous Issues has warned that "60 million indigenous people [worldwide] may be driven off their lands to make way for biofuels" (Ross, 2012).

Also, there is a concentration of income to producers and processors who make large profits compared to workers in the field, who usually receive low wages (Sawyer, 2008). The employees' work conditions undermine their health by causing severe exhaustion. Further, the displacement of family workers tears apart multi-functional family farms and traditional communities (Sawyer, 2008). In Brazil, "80% of sugarcane is cut manually by approximately 1 million seasonal workers" (Sawyer, 2008). To give an idea of how poor these workers' working conditions are, one finds that for a worker to make an average of $220 per month, he will have to cut an average of 10 Mg of sugarcane a day which is equivalent to swinging his machete 30 times per minute, for eight hours a day (Ross, 2012). Now, considering that the minimum monthly wage in Brazil for 2012 was R$622 (305 $US) (Byrne, 2012), under such conditions the workers would not even be making the minimum wage.

Some of the health repercussions of the manual harvest of sugarcane by these workers include "tendinitis and spinal column problems, loosening of the joints and spasms" (Ross, 2012). This is not to mention the respiratory problems that they may develop when sugarcane stubble is burnt, since the ashes can easily enter the respiratory

tract. The trade-offs between income and health are very dramatic, since some workers do not have many employment options and are compelled to risk their health to bring some food home to their families.

2.3.2 Food Security

As population growth has increased in the past decades, the demand for food has increased radically in many parts of the world. In order to cope with the demand, technologies such as the use of fertilizers, pesticides and improved crop varieties have been promoted. It was expected that by giving incentives to agriculture the total food demand would eventually decrease as a result of decreasing population growth (Hoogeveen et al., 2009). However, the increasing demand for biofuels resulted in an increasing demand for agricultural products (Hoogeveen et al., 2009). This in turn created a dramatic increase in food prices between 2005 and 2008, which, in turn, had a negative impact on food security. This situation was particularly devastating to the urban or landless poor (Hoogeveen et al., 2009).

Brazil's 2005-2006 increase in sugarcane production led to a lesser production of tomatoes (*Solanum lycopersicum L.*), peanuts (*Arachis hypogaea L.*), and oranges [*Citrus* × *sinensis* (*L.*) Osbeck] in the São Paulo city, and resulted in a decrease of coffee (*Coffea arabica L.*) production in Minas Gerais, Espirito Santo, and São Paulo (Ross, 2012). Moreover, there is no evidence that increasing income in Brazil through biofuel exports will reach the poorest people in the society. Indeed, in the 1970s, when north-eastern Brazil's Pernanbuco State lead the country in sugarcane production, it ranked among the poorest regions in the world (Ross, 2012). Food security is closely linked with ethanol production, not only in Brazil, but also in the United States. If the USA increases production of corn instead of that of other food crops, the weight of the food demand will be put on crop-exporting countries such as Brazil. Relying on food crops can only increase the vulnerability of the poorest sectors in Brazil since a small increase in food prices can dramatically change food availability to households.

2.3.3 Indigenous Populations: Guarani-Kaiowa

The Mato Grosso do Sul region of southwester Brazil is currently seeing a rapid expansion of soybean and sugarcane cultivation (Frayssinet, 2012). The Guarani-Kaiowa people have lived in this territory for many years and now are being threatened by the expansion of farms and landowners' violence towards them. A study carried out by a local Brazilian NGO 'Reporter Brasil' showed that there have been disputes over commodities and lands claimed by indigenous peoples, where landowners have resorted to armed attacks on native encampments (Frayssinet, 2012). The Federal Court of Navarai dispatched an order in September 29th 2012 to expel Guarani-Kaiowa communities from the riverside (Void Mirror, 2012). This decision has caused extreme violence towards this indigenous community, leading to their loss of any hope of getting their lands back. These peoples have concluded that since they will all die very soon, they would ask the Brazilian government to enact their collective death and bury them in their ancestral lands (Void Mirror, 2012). The news of this suicide threat was diffused globally in the past months and the government had the judicial decision revoked (Frayssinet, 2012). These indigenous people live in overcrowded conditions since only one hectare is allocated to the community (Frayssinet, 2012). Moreover, they don't have access to food, proper settlements, medical services or protection from farmer's gunmen (Frayssinet, 2012). Mauricio Santoro, a human rights adviser for Amnesty International in Brazil pointed out that: "These lands have not yet been demarcated by the federal government, and the legal vacuum has fuelled conflict" (Frayssinet, 2012). This lack of decision by the government can only exacerbate conflict and violence, the more they wait the more the lives of these communities are in danger. Moreover, according to CIMI (Conselho Indigenista Missionario) 555 suicides were recorded among the Kaiowa and other Guarani groups between 2003 and 2012 (Frayssinet, 2012). In terms of actions, so far the "Reporter Brasil" NGO has boycotted all companies illegally located on indigenous lands. Two ethanol plants have promised not to purchase sugarcane that comes from indigenous areas; however, other plants refused to follow this practice as long as they are not legally compelled to do so (Frayssinet, 2012). This issue is one of the most important social issues associated with biofuel production from sugarcane in Brazil. Clearly economic gain and the expansion of biofuel production can threaten the lives of marginal indigenous peoples who have no say in the policies of this new market, and who would rather die than be expelled from their traditional homeland.

3. Discussion

This paper has discussed the history of ethanol and its implications on the economical, environmental and social spheres in Brazil. Although biofuels have many advantages over fossil fuels (e.g., reduction of greenhouse gas emissions, employment opportunities, market expansion, etc.), biofuels cannot be seen as 'the miracle solution' to the world's dependency on fossil fuels. Brazil was chosen as the focus country for this paper since it is quite distinct from its ethanol-exporting competitor, the United States. The implications of biofuels in Brazil are enormous and range from environmental degradation to food insecurity, to violations of indigenous rights. It is

important then to ask the question: Who benefits from the income of biofuel production? The answer is simpler than it seems. With an inequality-adjusted HDI (Human Development Index) of 0.531 (United Nations Development Programme [UNDP], 2013), which ranks it 85th in the world, Brazil is considered one of the most economically unequal countries in the world (Haslam et al., 2012), especially compared to the United States which ranks 3rd (UNDP, 2013). Brazil is one of the few places where one can see *favelas* from one side of a wall and luxurious skyscrapers in the other. The answer becomes obvious; the economic benefits go to the wealthy countries that can purchase ethanol and the wealthy landowners, producers and processors that are part of this market. In this way, biofuel production only helps to enrich the rich and impoverish the poor and indigenous people, while the environment is severely degraded. Brazil's government should keep in mind that their first mandate is to the people, and not to international markets or the economy. The people include everyone living or working in the country, particularly those whose rights are not being respected at this moment. The social problems Brazil's government has to address and hopefully resolve in the next decades have deep roots and it will take a great deal of government cooperation and policy development to protect workers and the environment, reform the social system to eradicate *favelas* and improve the society as a whole. This paper has shown that the negative implications of biofuel production are enormous and in this case the Brazilian government should reconsider the viability of such a market.

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