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Is Renewable Energy Sustainable: Case Study of the Product Life Cycle of Brazilian Ethanol

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Abstract: This paper analyzes the product life cycle of the production of sugar cane for ethanol fuel in Brazil, to determine its sustainability in the long term. I have used a case study methodology and qualitative analysis to break down important elements involved in the production of sugar cane ethanol in Brazil. These elements include renewable energy aspects, agricultural practices, and the consequences of production on society involved in the process. Brazil currently derives 46 percent of its energy from renewable sources, but it is questionable whether they are sustainable in the long run. In order to create this renewable source of energy, the conversion process involves manually burning sugar cane, and creates harmful emissions. The industrialization process of planting and harvesting sugar cane has increased the use of chemical and technology, having a profoundly negative impact on the ecosystem due to the chemical contamination of the waterways, genetic impoverishment, and soil erosion. In addition, workers are exploited, poverty has been exacerbated, and food prices have increased. Although the production of ethanol has many advantages, including the substitution of petroleum, the social consequences remain a matter of grave concern. The process of obtaining renewable energy includes ecological destruction and negative social effects that are externalities of the economic calculations, and the requirements of capital accumulation dominate decision-making.

Keywords: Sustainability, Ethanol, Renewable Energy, Brazil PróÁlcool Program, Environmental Degradation, Sustainable Agriculture, Labor Exploitation, Pollution

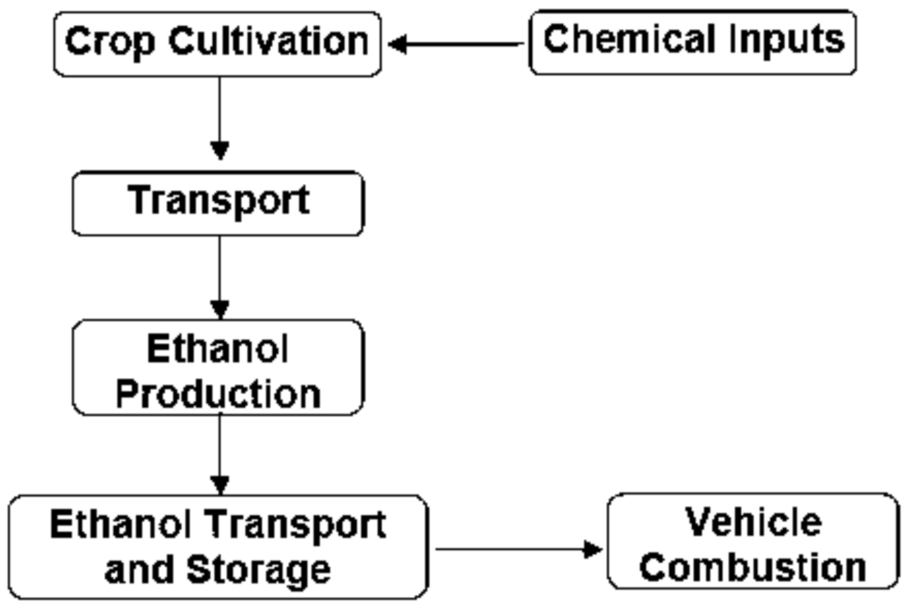
1. Introduction

Many countries are increasing their interest in biofuels for energy security and climate change reasons. Ethanol produced from sugar cane can replace imported oil, diversifying the sources of energy and bringing energy-security benefits to developing economies. [1]

However, the benefits of biofuels use remain uncertain. Although these fuels can significantly reduce emissions of greenhouse gases, the production of biofuels can have other negative impacts on society and the environment. [1] As a result, is it imperative that policies need to reflect the full life cycle of the production and use of biofuels on sustainability and the economy. [1]

In this paper, I will review the product life cycle of the production of sugar cane from ethanol in Brazil, to determine its sustainability in the long term. I will look at three main sectors involved in the production process: renewable energy aspects, agricultural practices, and the consequences of production on society. However, first it is important to have a better understanding of the country of focus, as well as background information on how ethanol became successful there. In addition, I highlight the important benefits of ethanol production that should not be overlooked when determining its sustainability.

Figure 1: Components for Sugar Cane Ethanol Produced in Brazil [2]



2. Background

Brazil is the largest Latin American country in terms of economy, population, and land area. [3] Brazil currently has a total population of 191.6 million inhabitants, with a gross domestic product of US$ 1,314.2 billion. Brazil is highly urbanized, with 85 percent of the population living in urban areas. Brazil also has a very inequitable income distribution and high poverty rates in some regions. [4] Unfortunately, 22 percent of the total population is below the national poverty line, and income inequality is a serious problem. Although its gross national income (GNI) is US$ 1,333 billion, the GNI per capita is US$ 5,910. [4]

As a result of the 1973 oil shocks of OPEC, Brazil launched the National Alcohol Program, or PróÁlcool, in 1975. This program provided lucrative incentives for the production of ethanol from sugar cane to decrease the dependency on foreign oil. [5] Brazil was burdened with a national debt of US$30 billion, and could not afford to import foreign oil after OPEC's price hikes. In addition, the world price for sugar fell from 50 cents a pound in 1973 down to 8 cents a pound in 1975, creating a massive surplus of sugar. Therefore, Brazil hoped the expanded PróÁlcool program would absorb the sugar surplus and create a decentralized fuel industry and stimulate jobs in rural areas. [6] The government provided ethanol producers with heavily subsidized loans to finance their capital investments, and was greatly expanded during the second oil shock in 1979. [3] This energy source is indigenous, renewable, and relatively inexpensive, leading the way to reduce Brazil's independence from foreign oil. As of 2009, Brazil derives 46 percent of its energy from renewable sources, with the world's largest infrastructure for the production and commercial distribution of ethanol. [7]

By 2000, Brazil was obtaining 9 percent of its energy from sugar cane. [3] Brazil had become the leading exporter of sugar in 2003. Sugar and alcohol exports increased from an annual average of US$1.7 billion in 1991-93 to 4.9 billion by 2005, due to the substantial contribution of ethanol. [8] Brazil cultivates one-third of the world's sugar cane, producing 416 million tons out of a total of 1.3 billion in 2004. Sugar cane plantations continue to expand, from 2 million ha in 1975 to 7.1 million ha in 2006. [9] It was estimated that 47 percent of the sugar cane harvested in 2007 and 2008 was used to produce sugar, and 53 percent to produce ethanol. [9] Brazilian cars can run off of straight ethanol, and all gasoline in Brazil is at least 22% ethanol (E22). [10]

Brazil has successfully reduced its share of imported oil from 70 percent in the 1970s down to 10 percent as of 2008. Sugar cane ethanol accounts for 50 percent of Brazil's gasoline consumption. [5] Currently, 90 percent of all new cars produced in Brazil are flex-fuel that run off of ethanol and gasoline. [5]

3. Benefits of Ethanol

Ethanol made from sugar cane has many positive benefits. It is a source of energy derived from renewable agricultural products, rather than nonrenewable fossil fuels, it is less toxic than gasoline and other alcohol fuels, and the incomplete oxidation by-products are less toxic than the by-products of other alcohol oxidation. Ethanol also produces much less sulfur and olefin emissions when compared with gasoline. Ethanol can be blended with gasoline to lower hydrocarbon emissions, and with diesel to decrease carbon monoxide emissions and particulate matter emissions. When the vehicle is not in use, ethanol also lowers levels of emissions resulting from evaporation because it has fewer highly volatile components than gasoline. [10] In terms of carbon dioxide alone, ethanol emits 70-75 percent less CO2 during engine combustion, significantly reducing the amount of greenhouse gases. [11]

Aside from the dramatic decrease of automobile emissions, ethanol is safer to store, transport, and refuel than gasoline. Because ethanol disperses and decomposes quickly, land and water spills are usually harmless. When compared to gasoline, this is extremely significant, as the amount of oil leaked from vehicles into rivers, lakes, and groundwater is estimated to be six times the annual volume of oil spills. [10] The impact from a major alcohol spill would be short and limited to a small area, and the amount of time alcohol would be present at toxic concentrations could be measured in hours compared to years for cruse oil or gasoline. Ethanol rapidly dilutes to low concentrations because it readily mixes with water, rather than forming a slick on the ocean surface, making the impact dramatically less. Also, fires caused by alcohol fuels are much less hazardous than gasoline fires because they can be readily extinguished with water. [6] Ethanol is not highly toxic to human health, and effects of exposure are typically ones of discomfort. [12]

In addition, the market for ethanol fuel adds $4.5 billion to farm revenue each year, employs over 200,000 people, and increases tax revenue by $450 million. [10] Ethanol production provides a stimulus for agriculture by the creation of incentives for increasing production and farmers' incomes, in addition to upgrading the infrastructure and availability of services to farmers. It also supplies fuel to support farm mechanization and the use of equipment when gasoline is either unavailable or too costly. [13]

Ethanol from sugar cane is much more efficient than ethanol from other products, such as corn in the United States. [10] The energy balance for sugar cane ethanol is positive, as the ratio between produced and consumed energy through out the process is 9.3, while for corn it is only 1.4. Ethanol exports from Brazil amounted to a yearly average of US$ 1.6 billion since 2005. [14] It is also economically viable, as production costs are currently 30 US cents per liter, making it much cheaper than corn. [15]

Table 1: Energy Ratio for Ethanol Production [14]

Sugar Cane	9.3
Corn	1.4

Ethanol is also useful in a variety of ways. It can be burned as an energy source, used as a chemical feedstock to derive a wide range of important organic compounds, and used as a solvent, germicide, or antifreeze. [16] Ethanol can be created by fermentation process from any material in which the carbohydrate is present in the form of sugar, yet the most common industrial processes use a petroleum by-product, such as ethylene. Fermentation is the microbial conversion of sugar to ethanol. The thermo-chemical process uses heat and pressure that causes a chemical reaction in the biomass to produce fuels, and then the alcohol is distilled to remove all water and impurities. [16] For each ton of sugar cane, 70-90 liters of ethanol are obtained for fuel. [13]

When evaluating the product life cycle of sugar cane ethanol, it is important to assess the resource consumption during the whole life cycle of products and services. Analysis previously conducted concludes that the environmental load rate is 45, which is extremely high due to the amount of pesticides used along with the high energy value of cars. Although it is a renewable fuel, the renewability of ethanol is only 2 percent because its production process is highly dependable on nonrenewable inputs such as agro-chemicals, fossil fuels, and steel machinery. Finally, a sustainability index of 0.02 was found. This demonstrates that the non-renewable energy demand is much bigger than the natural renewable energy income. Although the sustainability index provides useful information on resource consumption based on energy analysis, it does not include all aspects for a whole sustainability analysis. [17]

Table 2: Comparison of fuel alcohol production indexes to fuel alcohol life cycle (per liter of ethanol produced) [17]

Indice	Production	Life Cycle
Life Cycle Transformity (sej/kg)	6,7.1012	2,23.1013
Life Cycle Environmental Load Rate	2.46	45.23
Life Cycle Renewability	29%	2%
Life Cycle Energy Investment Rate	2.42	31.77
Life Cycle Energy Yield Rate	1.41	1.03
Life Cycle Sustainability	0.57	0.02

4. Renewable Energy Aspects

In order to created ethanol, sugar cane bagasse is burned to create energy in the form of heat or electricity. The leaves of the sugar cane are burned manually in the field, and the bagasse is placed in boilers with low pressure and temperature to generate steam and electricity. However, the practice of manually burning sugar cane in the field yields social and environmental costs. [9] When sugar cane leaves and tops are burned, local air pollution is produced, creating health hazards from respiratory diseases. [3] Pre-harvest burning of sugar cane is severely polluting, as empirical evidence found substantially elevated levels of carbon monoxide and ozone in the atmosphere around cane fields in São Paulo. Concern has been expressed over the impact on public health form these emissions. The use of fertilizers and pesticides worsens the effects of nitrogenous emissions form fields. [18]

Table 3: Sugar Cane Straw Burning Emissions [2]

Emission Species	Emissions (g/tonne Cane)	GHG (gCO2e/mmBtu EtOH)	GHG (gCO2e/MJ EtOH)
VOC	1,332.80	2,287	2.2
CO	17,516.80	15,204	14.4
CH4	514.1	7,003.90	6.6
N2O	13.3	2,164.50	2.1
CO2	315,973	172,195	163.2
BiogenicCO2 Credit	-349,067	-190,230	-180.3
Total GHG		23,226	
GHG (gCO2e/MJ)			**8.2**

Microorganisms in the soil are also destroyed from the burning process. In addition, it drops the degree of humidity from 13 to 15 percent, according to the Brazilian National Institute for Space Research. [11] Federal and state legislation has imposes a target of 50 percent reduction of this practice to improve working conditions and reduce local air pollution. [9] In addition, large amounts of cooling water are required for the process of fermentation and distillation. [13]

After the sugar cane is burned, stillage produced from the distilleries is dumped into local waterways. Stillage is highly polluting due to its high biochemical oxygen demand (BOD) content and high amount of minerals, especially potassium. [12] For every gallon of ethanol produced in a distillery, 12 to 17 gallons of stillage were discarded, robbing the water of oxygen as it decomposed, killing fish and other aquatic life. [6] The total annual stillage output is roughly equivalent to the sewage of 60 million inhabitants. [16] Stillage residues contribute to thermal and water pollution and eutrophication of ponds and streams. [13] After the decomposition process takes effect, it produces a noxious-smelling hydrogen sulfide gas. Despite the foul odors from the pollutants, children continue to bathe in the waters, although local fishermen have suffered from the reduction of fish species. The government passed a law banning the dumping of stillage into waterways, but found that it lacked the manpower necessary for effective enforcement. Although alternatives have been proposed for the discharge of stillage, they include additional costs, which the sugar industry has not agreed to bear in order to continue maximizing profits. [6] Some of these processes include anaerobic treatment, which could drastically reduce the carbon footprint of ethanol production. The anaerobic treatment process creates biogas rich in methane through the conversion of organics. However, this process is rarely employed in Brazil. [19]

Other by-products aside from the stillage that are created from ethanol production are carbon dioxide and fusel oils. Carbon dioxide is produced in the fermentation process, and is usually vented to the atmosphere. For each 1,000 liters of ethanol produced, 575 kilograms of carbon dioxide is emitted into the air. Fusel oils are also generated in the fermentation process, but only 4 liters of fusel oil are produced for each 1,000 liters of ethanol. [13]

Table 4: By-products created from ethanol production [13]

Ethanol Production by-product	Amount per 1,000 liters of ethanol
Stillage	13,000-18,000 liters
Carbon Dioxide	575 kilograms
Fusel Oil	4 liters

Although most vehicle emissions from using ethanol are lower than fossil fuels, aldehyde emissions increase with ethanol concentrations. Formaldehyde and acetaldehyde emissions from ethanol cause eye irritation, respiratory problems, and nervous disorders. [10] In addition, Brazil, like other developing countries, does not have any regulation on aldehyde emissions. [12] Carbon monoxide is also emitted in exhaust gases. The percentage of carbon monoxide in exhaust gases from ethanol blends is 4.2 percent, which is lower than pure gasoline at 6.8 percent but continues to present a problem in terms of air pollution. [16]

Ethanol can reduce dangerous carcinogenic emissions, such as benzene and butadiene. Yet the effects of the increase of formaldehyde and acetaldehyde are harmful. Ethanol escalates ground-level ozone, also known as smog. Smog increases have been linked to a rise in illnesses, hospital visits, and even death. One heath study shows 200 more ozone-related deaths, 770 more asthma-related emergency rooms visits, and 990 more respiratory-related hospitalizations. [20] When acetaldehyde reacts with the OH radical in urban atmospheres, the peroxyacetyl radical is formed, which reacts with nitrogen dioxide (NO2) to form peroxyacetyl nitrate (PAN). Although PAN is not a criteria pollutant, it is known to be potent lachrymators and mutagens and is also a plant toxin more potent than ozone. Increased levels of PAN have been notably observed in Rio de Janeiro, demonstrating that ethanol may not be as beneficial to overall air quality as first proposed. [21]

Transportation of sugar and ethanol should also be included in the life cycle analysis. In Brazil, most ethanol is transported within the country by way of rail or pipeline. When ethanol is exported, it is shipped via ocean tanker. Transportation energy requirements and emissions are often excluded from life cycle analysis, but as we can see based on the data below, it requires a large amount of energy input and contributes to 22.5% of total GHG emissions. [2]

Table 5: Emissions summary for Sugar Cane Ethanol [2]

Sugar Cane Ethanol Components	GHGs (g CO2e/MJ)	% Emission Contribution
Sugar Cane Farming and Burning	9.9	37.2%
Agricultural Chemicals	8.7	32.7%
Sugar Cane Transportation	2.0	7.5%
Ethanol Production	1.9	7.1%
Transportation and Distribution	4.1	15.4%
Total	**26.6**	**100%**

5. Agricultural Practices

The Organization for Economic Cooperation and Development has defined sustainable agriculture in terms of social, economic, and environmental contexts. They conclude that:

sustainable forms of agriculture are characterized by the adoption of practices that use integrated management techniques which maintain ecological integrity both on and off the farm; are necessarily site-specific and flexible; preserve biodiversity, landscape amenity, and other public goods not valued by existing markets; are profitable to producers in the long-term; and are economically efficient from a societal perspective. [22, 59]

Sustainable agriculture is an agricultural practice that seeks to maintain the environmental and ecological integrity of the soil, water, and land while providing sufficient income to farmers through the intercropping of different crop species. In Brazil, this type of agriculture refers to the farming that maintains the quality and nutrients of the soil, permitting long-term use of each lot of land. [23] Unfortunately, these practices do not adhere well to the outside market pressures to maximize profits.

The industrialization process of planting and harvesting sugar cane has increased the use of chemicals and technology, having a profoundly negative impact on the ecosystem due to the chemical contamination of the waterways, genetic impoverishment, and soil erosion. [24] Renewable fuels could produce more greenhouse gases than traditional fuels if the emissions of an agriculture using fertilizers and chemical herbicides, the manufacturing process, and transport are all included. Renewable energy cannot be considered sustainable in the ecological or economic sense of the term if the production process creates more carbon dioxide emissions than traditional fuels. [11]

Fertilizer use in the cultivation of sugar creates environmental problems that include soil acidification, perturbation of the balance of soil nutrients, contamination of groundwater and surface water, pollution of downstream aquatic ecosystems, and the release of gaseous emissions. The main components of gaseous emissions occur as a result of denitrification and volatilization, releasing harmful nitrous oxides and sulfides into the atmosphere. [18] Pesticides contribute to some of the same environmental problems, such as the contamination of groundwater and surface water and the pollution of downstream aquatic ecosystems. However, pesticides also accumulate in the soils and impact biodiversity when they spread to non-target areas. Pesticide usage also affects human health, as the

World Health Organization estimates that there are 25 million cases of acute chemical poisoning in developing countries each year due to pesticide use in agriculture. [18]

The use of fertilizers and pesticides are dangerous for biodiversity, the quality of soil and water, and the health of humans. In the state of São Paulo, where the majority of sugar cane production takes place, the acidity of the soil has greatly increased, which has caused fruit cultivation and other crops to disappear. Brazil has also witnessed the lowering of the water table because of the monoculture of sugar cane. [11] Fish stocks have been drastically reduced, and the use of contaminated water has created additional health problems in rural communities. [22] Sugarcane cultivation also negatively impacts the quality of natural water resources by contributing to extensive vegetation clearing in the riparian zones of rivers and flood-plain wetlands, soil erosion and stream sedimentation, and the contamination of the water bodies with nutrients and other discharges from diffuse sources. [18] However, the use of fertilizers and pesticides has become more intense. In 1992, 69.44 kilograms of fertilizer per hectare were sold, which increased to 128.83 kilograms per hectare by 2000. Pesticide usage grew as well from 2.27 kilograms per hectare in 1997 to 2.76 kilograms in 2000, just three years later. [25]

Table 6: Sugar Cane Farming Chemical Inputs [2]

Chemical Type	Chemical Input (Btu/g)	Product Input Factors (g/tonne)	WTT Energy (Btu/tonne)	WTT Energy (Btu/mmBtu)
Nitrogen Fertilizer	45.9	1,091.7	50,133	31,054
Phosphate Fertilizer	13.3	120.8	1,604	880
Potash	8.4	193.6	1,624	892
Lime	7.7	5,337.7	41,019	22,512
Herbicide (average)	262.8	26.9	7,070	3,898
Insecticide (average)	311.3	2.21	688	379
TOTAL				**59,616**

Misuse of fertilizers and pesticides has caused human poisonings, as operators lack the education necessary to prepare themselves for the hazardous conditions. Most operators do not follow agronomic prescriptions, lack adequate protective clothing, smoke during the applications, store products in unsafe conditions, and wash their equipment in rivers, tanks, wells, or lakes. This is a result of a low level of training and education of the workers, coupled with inadequate working conditions. [22] A document prepared for the Ministry of Health stated that pesticide residues have been found in several agricultural products, including fruits, vegetables, potatoes, wheat, milk, beef, and canned beef. BHC residues were also detected in fish, shrimp, and oysters on São Paulo’s coast. There are several cases of poisoning of farm workers by pesticides for sugar cane, and cases of herbicide spraying has destroyed additional plantations due to wind action. Soil analysis also detected hazardous chemical residues. [22]

Other public health problems resulting from sugarcane cultivation are found in the water systems. Sugarcane irrigation systems are known to harbor schistosomiasis and malaria. Depending on the location of the sugar plantation, other infections, such as fascioliasis and paramphistomiasis, may become a problem to both humans and domesticated animals. [18]

Another technology that increases profits in sugar cane production is the introduction of genetically modified organisms (GMOs), whose risks are well known. Although they make production highly profitable by increasing production volumes, their extension into the monoculture of sugar cane risks endangering numerous species. In addition, their long-term effects have not really been calculated. Although the Brazilian government has attempted to impose brakes on their usage, the power of transnational corporations along with the fact that wind, insects, and other animals transport seeds has blocked these efforts. However, the increase in productivity has allowed firms to increase profits and accumulate additional capital. [11]

The monoculture of sugar cane also leads to other vulnerabilities in the soil, such as erosion and diseases, which necessitates the need for additional harmful pesticides. Soil salinization and acidification is increased, and is even more dramatic during the dry season when the water levels are lower, as crops dig deep into the water and transmit any mineral salts or pollutants that have dissolved on the surface. This results in an imbalance in the mineral nutrients of the soil, leading to the disappearance of calcium, magnesium, and potassium, while increasing the sodium content. The soil, therefore, becomes no longer suitable for agriculture. [11] Acidification is caused by the use of acidifying nitrogenous fertilizers, such as urea and ammonium sulfate, added to nitrate leaching caused by heavy rainfall. Salinization, however, is the greatest of concerns in sugar production because it can ultimately restrict plant growth all together. [18]

Soil is also lost in the harvesting process as it is removed from the field with the crop. Cultivation also causes the loss of soil organic matter and changes in nutrient levels. [18] Other problems in the soil that have been exacerbated by the mass mono-cropping of sugar cane are erosion, soil compaction, decreasing fertility, and chronic plant disease problems. [22] Soil erosion further contributes to land degradation, sedimentation of surface waters, and redistribution of organic matter and nutrient-rich material in the soils. [18]

In addition, fundamental forces of deforestation include the competition between humans and non-humans for land. The growth of the local market for agriculture products is responsible for the deforestation of the rainforest. [23] Although sugar cane production does not always directly cause the deforestation of the Amazon rainforest, it does cause deforestation indirectly. As land is extended for the production of sugar cane for ethanol, it displaces pastureland and small farms and pushes these farmers to wooded areas, particularly in the state of Amazonia. The Cerrado, one of the richest biodiversity areas in Brazil, has lost half its land surface in 40 years, while the country as a whole 162,000 hectares of what is called 'the conservation zone' have already been taken over by sugar cane production. [11] Due to the ProAlcool program, only 3 percent of the original rainforest cover remains in the state of Alagoas in Northeast Brazil. [18]

In addition, there has been a substantial amount of impacts on biodiversity and loss of natural habitats. Many areas have been cleared for the production of sugar cane, leading to the loss of rainforest, tropical seasonal forest, thorn forest, semi-desert scrub, and savannah, and land continues to be expanded for cultivation. [18] The loss of habitats triggers a range of wider impacts on the function of ecological systems, including changes to hydrology and increased soil erosion. As a consequence, sedimentation occurs in waterways and eutrophication is caused from the leaching and runoff of nutrients. Groundwaters are further affected by the leaching of nutrients from fertilizers, and these impacts are transferred downstream and affect other ecosystems. [18]

6. Consequences on Society

Poverty in the agricultural sector has been exacerbated, due to the unsustainable technologies over a highly concentrated agrarian structure and a social structure that favors the wealthy elites, along with the destructive farming techniques. These practices have depleted natural resources while reducing potential sources of income for present and future generations. Although some institutions have taken positive steps to reduce these conundrums, they remain inadequate to actually provide sustainable solutions. [22]

After the PróÁlcool Program was initiated, the elite of São Paulo and Rio de Janeiro gained full control of sugar industry and accounted for 60 percent of all cane production. Independent growers in the Northeast were dominated politically and economically, as they were unable to keep up with the production levels of the elite power. Therefore, many impoverished small farmers were simply put out of business. [26] Many independent farmers were forced to rent or sell their land to the sugar and ethanol industrialists, leading to higher levels of land concentration. Government subsidies from the PróÁlcool Program swallowed up the land of many small farmers. With easy access to subsidized credit, producers of ethanol have been able to greatly expand their land capacity at the expense of smaller farmers, leading to further concentration of land and income that widened the gap between independent farmers and mill owners. [26] Although Brazilian officials claimed there would be no competition for land between food crops and energy crops, the problem came to surface in 1980 when Brazil was forced to import black beans from Mexico because bean cropland in the south had been turned over to sugar for alcohol production. [16]

As small-scale agriculture is destroyed by land concentration, peasants are forced to become legal or illegal colonizers of forest areas while others migrate to urban slums. According to the United Nations Permanent Forum on Indigenous Issues, over 60 million people in the world are at risk from being expelled from their land solely for the production of agrofuels. [11] This adds to growing problems with urbanization, as migrants are forced to live in squatter settlements in the slums, and crime and violence increase when people are unable to feed their families. [27] Urban sprawl further causes environmental destruction and the contamination of water sources because their places of residence do not provide basic necessities, such as water and sanitation. [28]

The level of exploitation of workers is a form of slavery in many sugar plantations in Brazil. Laborers are often subject to inhumane working conditions, as they work for seven days a week for a wage equivalent to US$2.50 a day. The Movement of Landless Workers published a study in 2008 stating that every ten minutes the workers cut 400 kilograms of cane, with 131 blows of the machete, requiring 138 body movements. [11] Therefore in one day, it amounts to the cutting of 11.54 tons of cane, 3,792 blows of the machete, and 3,994 body movements, resulting in heart fatigue. Breaks are allowed every 30 minutes, although they are not respected. This creates serious health risks for workers, as this type of work affects their life expectancy. Children are also susceptible to this slavery-like labor. These workers are forced to work in deplorable, sub-human conditions that do not respect fundamental human rights, yet women workers are even more discriminated against and are paid less than the men. [11]

A political scientist in Rio de Janeiro stated that slavery still exists today in Brazil, especially in the sugar industry. [29] Ironically, one day after BBC News published that interview, Brazilian authorities rescued 95 farm workers who were kept in slave-like conditions, 44 of which were found in a sugarcane plantation. These workers were found in the states of Rio de Janeiro and Minas Gerais with no clean drinking water or safety equipment. All of the workers were not registered. Similarly in 2008, 5,266 workers were rescued from living in near-slave conditions, and it is likely that there is four to five times more. [30] Experts estimate that some 25,000 people in Brazil still work in slave labor conditions. Last year, some 3,000 workers were rescued across the country of Brazil. Although the Brazilian government launched a plan to eradicate slavery in 2002, many of these instances continue in the sugar industry. [31]

Aside from the physically extreme exploitation of workers, they are also paid at a minimum level, without social security or pension. Workers' unions are forbidden, and if workers are able to unite they are rendered ineffective by means of repression or corruption. In order to maximize profits and appropriate the added value, firms continue to put pressure on all elements pertaining to the cost of production to reap higher benefits. The social costs of operating and producing ethanol are not included in the capitalist accountancy. [11]

Although sugar cane production has provided increased employment opportunities, it has led to unemployment as it has driven out other crops and their producers from these areas. [26] In addition, the Institute of Agricultural Economics of the state of São Paulo administered appreciable declines in real wages, diminishing the hopes of migrant workers to improve their conditions. Sugar harvesters are forced to migrate several times a year to find work due to sugar cane monoculture in the fields. [26] In 2005, there was a loss of 300,000 jobs in agriculture, creating further problems of migration, urbanization, and pressure on the agricultural frontier. [11]

Another harsh impact on society from the production of ethanol is the rise in food prices. In 2008, there were 854 million people suffering from hunger because of poverty and 2 billion others who were malnourished. In the period between 2007-08 more than 115 million people fell below the poverty line, and the increasing process of food continue to contribute to these horrific statistics. [11] The rise of prices is caused by disequilibrium on the supply or the demand of food crops. Increased production of ethanol puts pressure on both the supply and demand for food. As more sugar cane is planted, the volume of other food crops is reduced, putting pressure on demand. [11] The supply side is also affected as massive sugar cane production has pushed food production further away from urban centers, increasing transportation and production costs for food crops. Food substitution has lead to higher prices for other agricultural goods, and the real cost of food rises. As workers are forced to spend more of their income on food, their purchases of industrialized goods decrease. The demand for manufactured goods decreases, which slows the overall process of economic growth. Brazil's poor is most affected by the higher food prices and are forced to spend over 40 percent of their income on food. [26]

In addition, crop substitution puts pressure on the costs of food and land. It also reduces the amount of credit available, which increases the cost of money for other purposes. This inflates the costs of food, land, credit, and fuel, which hit the impoverished much harder than the rest of the population. It has increased the concentration of wealth by supplanting food crops and adding to the inflation. As a result, ethanol production has negatively redistributed real income. [26] In addition, if food imports are not increased, using agricultural land for fuel production may cause serious food supply problems. [12] Neo-Malthusian theorists aid this battle by arguing that biofuels are the main driver of the current food crisis. [15]

7. Conclusions and Recommendations

Sugar cane production created a further concentration of land, production, income, and wealth. Although the production of ethanol has many advantages, including the substitution of petroleum, the social consequences remain a matter of grave concern. The question remains if social efficiency and economic efficiency are mutually exclusive. The production of ethanol represents enormous sunk costs, requires high operational expenses, and has few prospects to be economically competitive with fossil fuels. [26]

A bottom-up approach which includes farmers in the decision making process is key to the success of the ethanol program. In addition, micro-loans can provide much needed finance to aid the farmers and help them become self-sufficient in order to maintain sustainable practices. Educational programs can provide incentive for farmers to adopt sustainable techniques, as a study found that farmers who have a greater number of completed years of education are more likely to adopt sustainable agriculture. [23] Although the Brazilian government was the chief decision-maker for the PróÁlcool program, they failed to consult with the parties that were most affected by the program. Their impact on land tenure has increased the concentration of rural wealth, and the program has been considered to assist the car-owning elite class. Therefore, this program has done little to promote economic development and reduce the massive social inequalities in Brazil, and it appears to have helped maintain them. [16]

An economic solution would be to attach a quantitative weight to human desires and preferences, or consider the full cost of the degradation to society and the environment on a price system. [22] The government, local community, and the sugar industry should share responsibility for natural resource management in a transparent manner to assure effectiveness. The government should also establish appropriate incentives to encourage community members and firms to protect natural resources and encourage sustainability. These incentives should vary according to the issue and local, regional, and social characteristics by taking different forms, such as motivational, voluntary, property-right, price-based, and regulatory instruments. The community should also contribute to the provision of incentives to the sugar producers by becoming actively involved by reporting any wrongdoings. [18]

It is important that government at all levels show commitment to sustainable development, as well as develop the necessary supporting institutional capacity to enforce such regulations. In addition, the local community and industry must be informed, empowered, and enabled to properly manage resource consumption. After all groups are involved in the decision-making process, proper monitoring and accountability should be in place to ensure effective implementation. [18]

To increase the sustainability of fuel ethanol from sugar cane, it is necessary to lower the use of toxics in fertilizers and chemicals, substitute the use of fossil fuels used in the transport for fuel alcohol as well as in agricultural equipment, incorporate green areas, and improve social conditions. [17]

Conflict of Interest

The author declare no conflict of interest.

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