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Technology Collaboration Programme

Biofuels in Emerging Markets

Potential for sustainable production and consumption

IEA Bioenergy: Task 39

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IEA Bioenergy

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Biofuels in Emerging Markets

Potential for sustainable production and consumption

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Executive Summary

A great potential exists for biofuels in emerging economies of Latin America, the Caribbean, Africa and Asia as these regions have a growing demand for sustainable energy, plentiful local resources and land availability to produce biofuels. As society adapts to the low carbon economy needed to meet the targets in the fight against climate change, it is crucial to understand how sustainable biofuels are in the several contexts that they are being produced across the globe. In this study we evaluated policy frameworks and biofuel mandates across the global south. Policy environments were classified into three categories: fully implemented biofuels market, partially implemented biofuel blending mandates, and a positive policy environment where a legal framework is in place.

A methodology was developed to evaluate the sustainability of biofuels production, which included an Attributional Life Cycle Assessment (LCA) to verify reductions in greenhouse gas (GHG) emissions and a Techno-economic Analysis to verify economic feasibility. This report presents the results for biofuels produced at scale, in large commercial quantities (High Technology Readiness Level) in Argentina, Brazil, Colombia and Guatemala. Biofuels included in the analysis were ethanol and biodiesel from corn, sugarcane, soybean, and oil palm.

Argentina has a New Biofuels Law in place for blending mandates and is currently adopting E12 and B5 using corn ethanol and soy biodiesel. Brazil has the RenovaBio National Policy of Biofuels Law that certifies and rewards producers that reduce emissions with decarbonization credits. Brazil uses hydrous ethanol, E27 with anhydrous ethanol from sugarcane, and B10 with biodiesel mainly from soybean oil and tallow. Colombia has legislation in place for ethanol and biodiesel and is currently adopting E10 and B10 using sugarcane and oil palm. Guatemala intends to implement a 10% ethanol blend in gasoline in 2024.

Land use for biofuel crops, food crops, and pastures was evaluated as well as the potential land needed to duplicate biofuels production in these countries. The total land used in Argentina, Brazil, Colombia, and Guatemala for biofuels production corresponds to 4.6%, 6.3%, 0.2%, and 10%, respectively, of the land used for pastures. Conversion of small portions of pastureland (from 0.1% to 10%) could add significant land for biomass feedstocks and double biofuel production. The payback time for soil carbon stocks of the pasture to sugarcane transition is around 2 to 3 years. Our analysis highlights best practices that if used can contribute to environmental benefits by decreasing emissions and helping land recovery.

The LCA indicated a 70% reduction in GHG emissions when sugarcane ethanol displaced gasoline and a 37% reduction when corn ethanol displaced gasoline. A 73% reduction in emissions was observed when soybean biodiesel displaced fossil diesel and an 84% reduction was observed when palm oil biodiesel displaced fossil diesel. Sensitivity analysis showed that the use of fertilizers is the main factor contributing to GHG emissions in biofuel production. The techno-economic assessments showed a consolidated and feasible industry in all biofuel cases reported here. The minimum selling prices show competitiveness with gasoline and diesel prices and a high sensitivity to feedstock prices.

The study also considered the end-use aspects of biofuels. Flex-fuel vehicle technology allows consumers to choose between gasoline and ethanol according to fuel prices, availability, and preference. Hybrid ethanol vehicles are now available alongside electric vehicles, but flex-fuel engines continue to compose most of the new fleet. Renewables are growing to provide electricity, and bioenergy is an increasingly important option as it can provide fuels with a high energy density that can be stored, fit in the present infrastructure, and provide building

block molecules for different applications. Fleet sustainability needs to consider aspects that go beyond GHG emissions including economic feasibility. Flex-fuel technology has been an enabler of biofuels use and contributes to decrease pollution in cities, an important problem in many emerging economies. Incentives focusing on reduction of emissions of GHG through transport electrification may lead to overload of the electric grid since the infrastructure is not sufficient to supply the domestic demand and an electric fleet. Moreover, there are concerns related to acquisition costs of electric vehicles in these markets.

The economic impact of low carbon policies was also evaluated. Together, the four countries are avoiding 68 $MtCO_2eq$. For instance, if credits for 1 tonne of avoided CO_2 emission were sold at \$10, biofuel producers in Brazil would earn \$599 million per year, and biofuel producers in Argentina, Colombia, and Guatemala would obtain additional profits of approximately \$58, \$21, and \$3 million, respectively, based on their respective productions in 2019. We used the RenovaBio Program as an example to demonstrate that trading mechanisms for avoided GHG emissions are important to reduce overall emissions around the globe.

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1. Biofuel policies across the global south

Today's energy challenge involves using a combination of options to decarbonize transportation including modern bioenergy. Bioenergy harnesses solar energy through photosynthesis to capture CO_2 and convert it into renewable energy. Bioethanol, biodiesel, renewable diesel, biogas, biomethane, biohydrogen, biomass heat and bioelectricity are among the most common products of this sector do the economy.

Across the world, countries have introduced biofuel blending mandates, many in developing regions (Fig. 1).[1] Biofuel markets across the globe are rapidly evolving, at rates higher than those observed for conventional fossil fuel market. For instance, the production of ethanol and biodiesel in 2010 was equivalent to 60.1 million tons of oil equivalent (Mtoe), and in 2020 it reached 89.7 Mtoe, representing an annual growth rate of 4.9%.[2]

Energy security concerns and increasing energy demands are the most common incentives for emerging economies to seek local solutions to keep up with their economic and social growth, while preserving the environment. In this context, the development of bioenergy has been playing a fundamental role in enabling sustainable development strategies. This has been especially the case in Latin America, where an estimated 360 million ha of spare and usable marginal land is available. This region also displays modern agricultural practices that, with yield increases, created conditions that allowed for this continent to produce more food than it needs and to export food products to the rest of the world.[3]

Considering policies, local infrastructure, land availability, crop yields, technology readiness level, techno-economics and climate impacts several studies have described the potential for expansion of biofuels in Latin America. We describe here some of the findings for ethanol and biodiesel in Argentina, Brazil, Colombia, and Guatemala.[4,5]

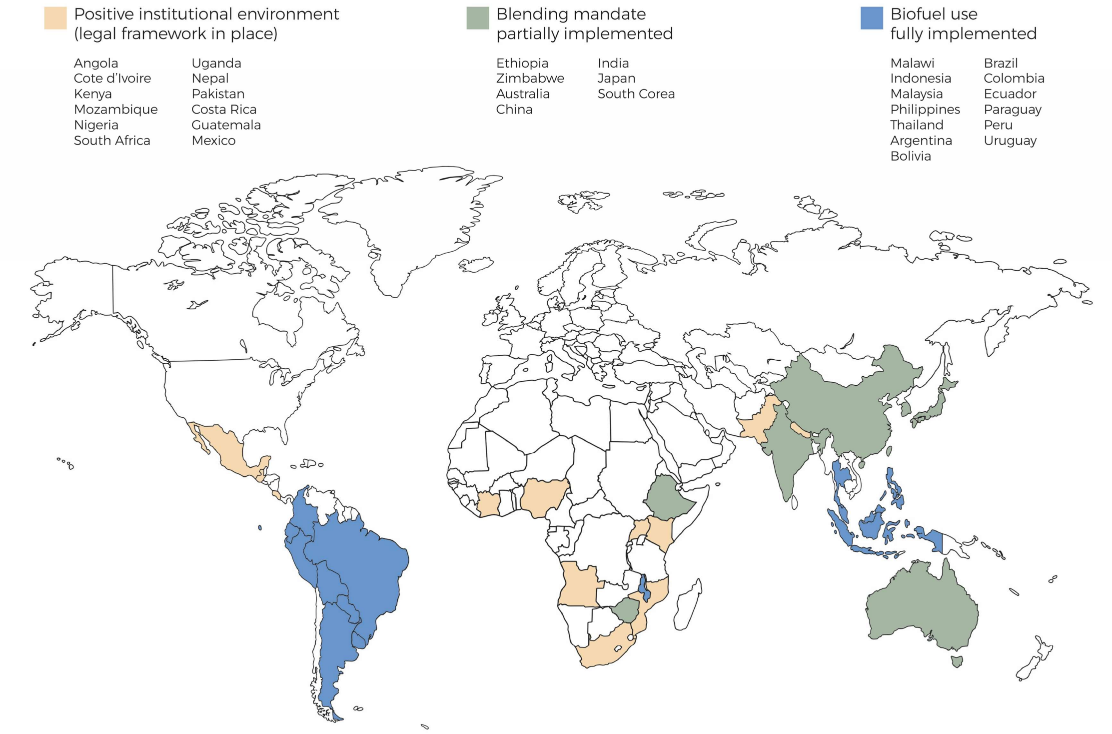


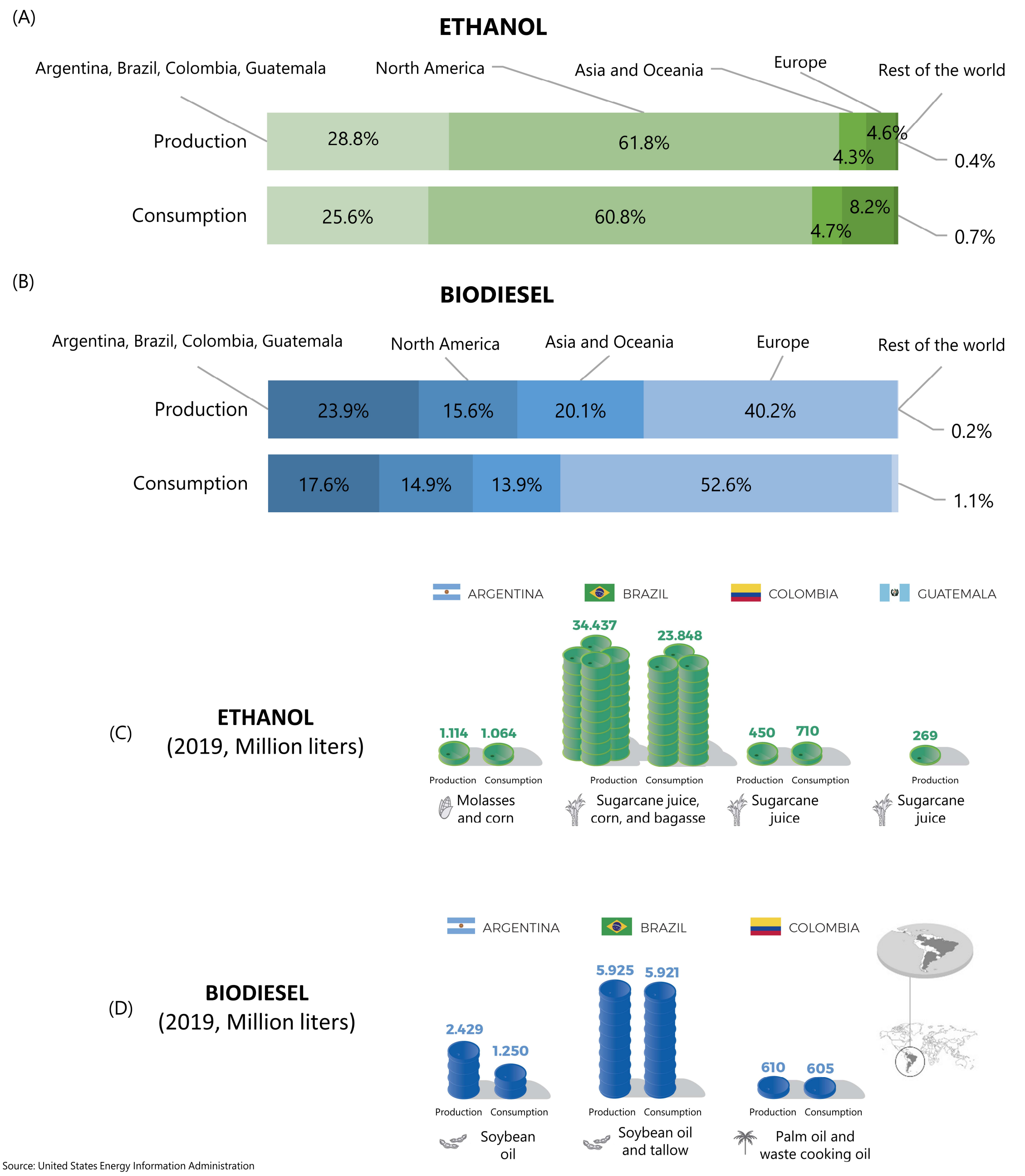
Fig. 1 – Adoption of biofuels blending mandates. Focusing exclusively on the developing countries of Africa, Asia, Latin America and Oceania, the map shows adoption of liquid biofuels blending mandates (ethanol in gasoline and biodiesel in diesel). Three categories were considered, from the most consolidated case to the case in which the implementation is starting: 1) countries where biofuel use is fully implemented, with a blending mandate in place, a regular market of biofuels is established, liquid fuel terminals are operating normally (in blue); 2) countries where the use of biofuels is already implemented, with a blending mandate in progressive adoption, a regular market for biofuels begins to be created, not necessarily throughout the country (in green); 3) countries where the legislation and regulation for promoting use of biofuels is approved, in some cases with schedules and programs to adopt blending mandates, and where typically a debate is taking place among consumers, fuel distributors, biofuel producers on the convenience, risks and advantages of biofuels (in orange). As it can be observed, across all South America (except for Chile and Venezuela) the use of biofuels is mature and well established, as occurs in Malawi, Indonesia, Malaysia, Philippines and Thailand, countries with decades of experience with liquid biofuels. Then come those countries implementing blending programs, in some cases starting with low level blends and not in all country territory, accumulating know-how and progressively clarifying doubts and overcoming barriers. The third group includes those countries with a positive legal framework to advance, conducting pilot and demonstration programs to go ahead in more effective and real biofuel use, as can be observed in Central America and Africa (Adapted from Trindade et al., 2019).[1]

2. Energy Matrix & Policy Outlook of Biofuels in Latin America

Table 1 – Latin American socioeconomics and energy mix. Latin America in general, and Argentina, Brazil, Colombia, and Guatemala specifically, have a transportation and electricity mix less dependent on fossil fuels than the rest of the world. Bioelectricity's contribution to the electricity mix in Latin America (9%) is double of the share observed in the world (4%) and three times the share observed in OECD members (3%). This difference becomes more apparent when considering Argentina, Brazil, Colombia, and Guatemala (12%). The same trend is observed in the transportation sector, where biofuels contribute with 20% of the mix while in the world this share is 2.5%. Nevertheless, oil products (gasoline and diesel), dominate the energy mix of the transportation sector, and the contribution of biofuels remains limited to 9%, 23%, and 7% for Argentina, Brazil, and Colombia, respectively. Guatemala is unique in its approach since biofuels are not used internally. About 80% of the ethanol produced in Guatemala is exported while all the gasoline and diesel consumed are imported from the United States. Some studies argue this paradox as an example of barriers to implementing biofuel blending mandates because of costs of the ethanol-gasoline blend relative to the price of gasoline and the lack of appropriate policy support.[6]

	World	OECD	Latin America and Caribbean	Argentina., Brazil, Colombia, and Guatemala
Population (millions)[7]	7837	1376	658	328
Propulation growth (annual)[7]	0.88%	0.21%	0.94%	0.77%
GDP per capita (US$)[7]	12263	42099	8340	7620
HDI[8]	0.732	0.899	0.754	0.759
Energy sources in transport[7]	Oil (93%) Natural gas (4%) Biofuels (2.5%) Electricity (1%)	Oil (89%) Natural gas (4%) Biofuels (5%) Electricity (2%)	Oil (80%) Natural gas (5%) Biofuels (15%)	Oil (74%) Natural gas (6%) Biofuels (20%)

	World	OECD	Latin America and Caribbean	Argentina., Brazil, Colombia, and Guatemala
Electricity mix (main sources)[7]	Coal (44%) Nat. gas (24%) Nuclear (13%) Hydro (7%) Bioenergy (4%) Solar/wind (3%) Oil prod. (3%)	Coal (19%) Nat. gas (30%) Nuclear (17%) Hydro (15%) Solar/wind (13%) Others (6%)	Hydro (34%) Oil prod. (12%) Nat. gas (27%) Bioenergy (9%) Coal (5%) Solar/Wind (5%) Nuclear (4%)	Hydro (39%) Oil prod. (4%) Nat. gas (29%) Bioenergy (12%) Coal (8.5%) Nuclear (6.5%)
Energy use, total (EJ)[7]	594	227	34	18
Energy use, per capita (GJ)[7]	76	165	52	54
CO_2 emissions, total (Gt)[7]	35.59	11.55	1.79	0.78
CO_2 emissions, per capita (t)[7]	4.54	8.39	2.71	2.39
CO_2 emissions, transport (Gt)[7]	7.19	3.24	0.64	0.32
CO_2 emissions, in transport per capita (t)[7]	0.92	2.35	0.97	0.96



Source: United States Energy Information Administration

Fig. 2 - Biofuels from Argentina, Brazil, Colombia, and Guatemala. Around 28% of the global production of liquid biofuels takes place in Central and South America. Argentina, Brazil, Colombia, and Guatemala are responsible for 24% of the global production of biodiesel and 29% of the global production of ethanol (Fig. 2A and 2B). Most of this production is consumed internally by these countries, except in the case of Guatemala, which exports most of its ethanol (Fig. 2C and 2D). Argentina, Brazil, and Colombia have biofuel programs fully implemented. Guatemala does not adopt a national biofuel program yet and intends to start using a 10% ethanol blend in gasoline in 2024. In June 2022 Brazil had 325 sugarcane ethanol mills, nine sugarcane/corn ethanol mills, nine corn ethanol mills, and 57 biodiesel plants (authorized to operate).[9] Guatemala had five mills and Colombia had six mills producing ethanol from spent molasses.[10] Argentina had 18 (corn and sugarcane) ethanol mills and 37 biodiesel plants.[11]

Table 2 – Biofuel Programs in Argentina, Brazil, Colombia and Guatemala[1].

Country	Biofuel Program	Status
Argentina	New Biofuels Law 27640 (July 2021) for biofuel blending mandates. Currently adopting E12 and B5 using corn ethanol and soybean biodiesel.	Implemented. Argentina exports biodiesel to the US, Europe and Latin American countries.
Brazil	RenovaBio National Policy of Biofuels Law nº 13.576/2017 (since 2020) certifies and rewards producers with decarbonization credits (see Fig. 3 for an explanation on RenovaBio). Currently adopting pure hydrous ethanol, E27 with anhydrous ethanol from sugarcane, and B10 with biodiesel mainly from soybean oil and tallow.	Biofuels are consolidated in the Brazilian energy transport mix. Mandates are fully implemented. Flexible Fuel Vehicles represent about 80% of the light vehicles fleet (37.9 million units).
Colombia	Law 939/2004 for biodiesel and Law 693/2001 for ethanol. Currently adopting E10 and B10 with sugarcane ethanol and palm oil biodiesel.	Implemented.
Guatemala	Guatemala does not adopt a national biofuel program yet.	Planning to start in 2024.

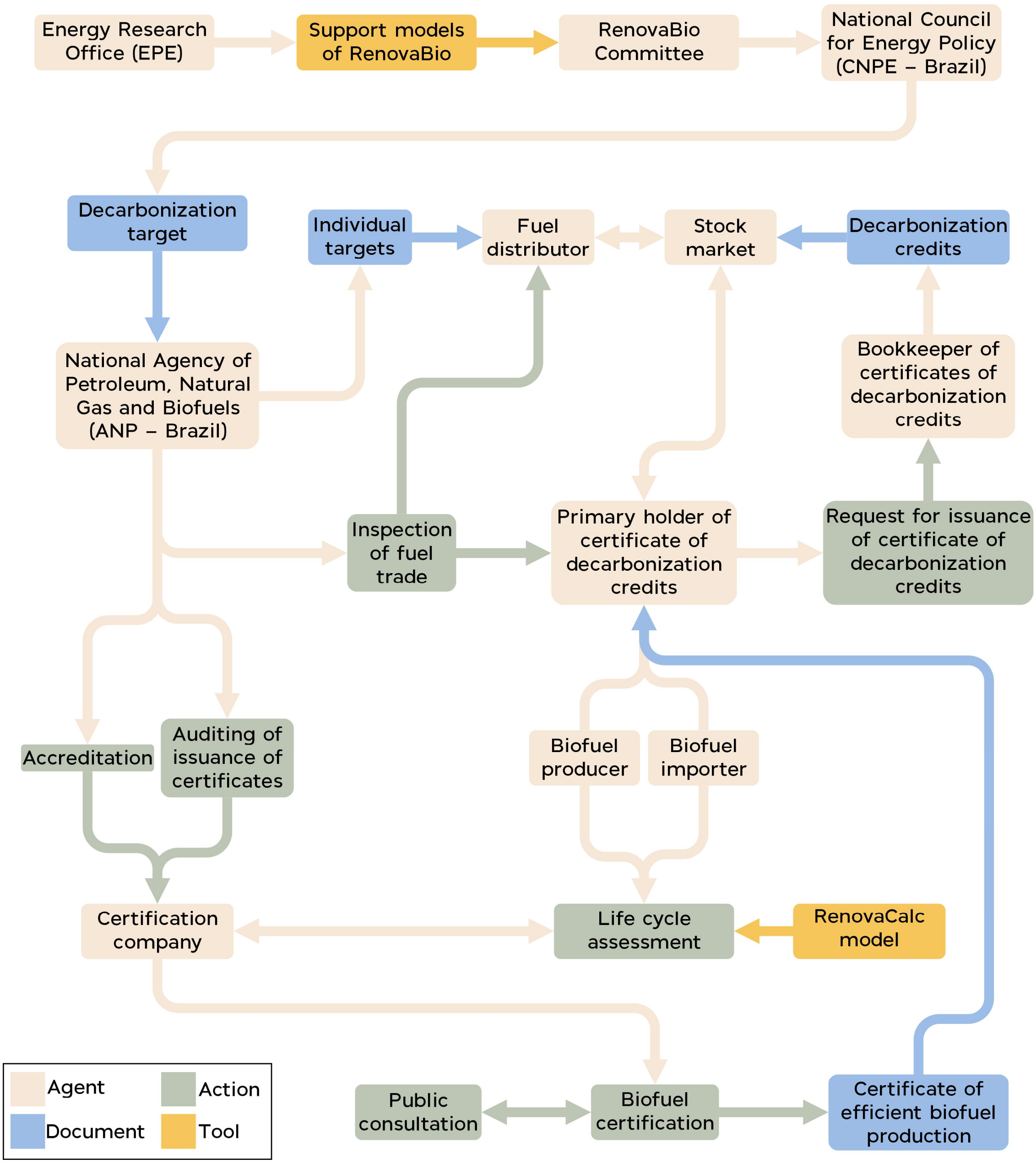


Fig. 3 - The Brazilian National Biofuels Policy Framework (RenovaBio). RenovaBio is a public policy that recognizes the importance of biofuels in fulfilling the Brazilian pledges to reduce emissions agreed at COP 21. Annually, the federal government establishes national targets for decarbonization and shares the target for the transport sector among fuel distributors according to their market share. Ethanol, biodiesel, and biogas producers, on the other hand, have the CO_2 emission mitigation of their production certified by independent companies based on the LCA provided by the RenovaCalc model, obtaining grades proportional to the environmental efficiency of their processes. This score allows biofuel producers to issue mitigation credits (CIBIOs) according to their production. These credits are tradable in the stock market to permit fuel distributors to meet their decarbonization targets; otherwise, they suffer legal actions. Since the beginning of the program in 2020, 75 million CIBIOs have been issued.

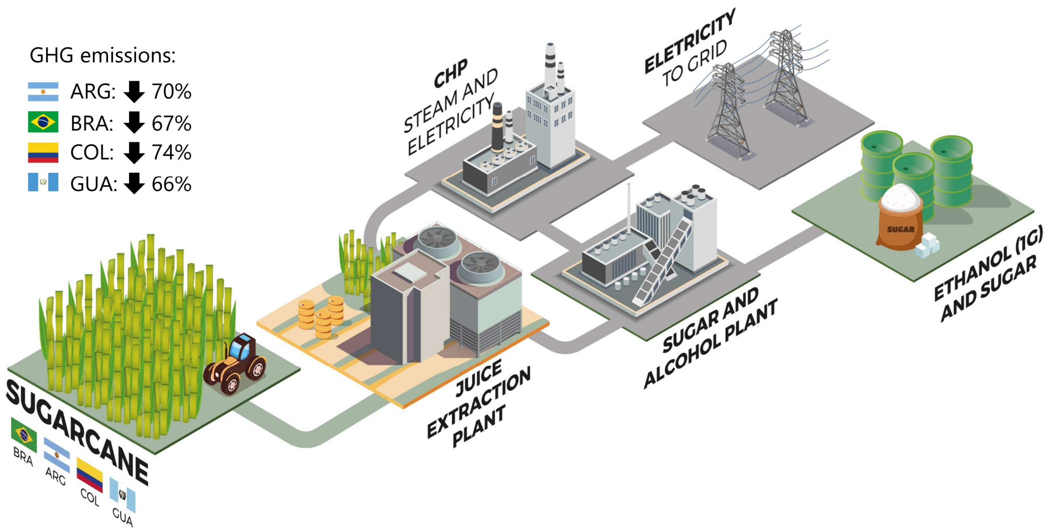
3. Technological Routes

Technological routes and system boundaries for LCA and GHG emissions of ethanol compared to gasoline and biodiesel comparrf to diesel were assessed including techno-economic indicators. Feedstocks evaluated were corn, sugarcane, soybean, and oil palm. The LCA indicated a 70% reduction of GHG emissions when sugarcane ethanol displaced gasoline and a 37% reduction when corn ethanol displaced gasoline. A 73% reduction of emissions was observed when soybean biodiesel replaced fossil diesel and an 84% reduction was observed when palm oil biodiesel substituted fossil diesel. Sensitivity analysis demonstrated that fertilizers are the main contributor to GHG emissions in the production of biofuels.

Net Present Value, Internal Rate of Return, and Minimum Selling Prices indicate in all evaluated cases for the four countries a consolidated and economically feasible industry. The minimum selling prices for ethanol (0.34 to 0.39 USD_{2019}/L) and biodiesel (0.46 to 0.57 USD_{2019}/L) show competitiveness with gasoline and diesel prices in these regions and a high sensitivity to feedstock prices.[5]

The economic impact of low carbon policies was also evaluated. Using the RenovaBio Policy Program it is possible to estimate large revenues for producers if they were rewarded for avoided emissions. Together, using the routes described in Fig. 4 and Fig. 5, the four countries are avoiding 68 $MtCO_2eq$. For instance, if credits for 1 tonne of avoided CO_2 emission were sold at $10, biofuel producers in Brazil would earn $599 million per year, and biofuel producers in Argentina, Colombia, and Guatemala would obtain additional profits of approximately $58, $21, and $3 million, respectively, based on their respective productions in 2019. We used the RenovaBio Program as an example to demonstrate that trading mechanisms for avoided GHG emissions are important to reduce overall emissions around the globe.

PATHWAYS FOR ETHANOL PRODUCTION



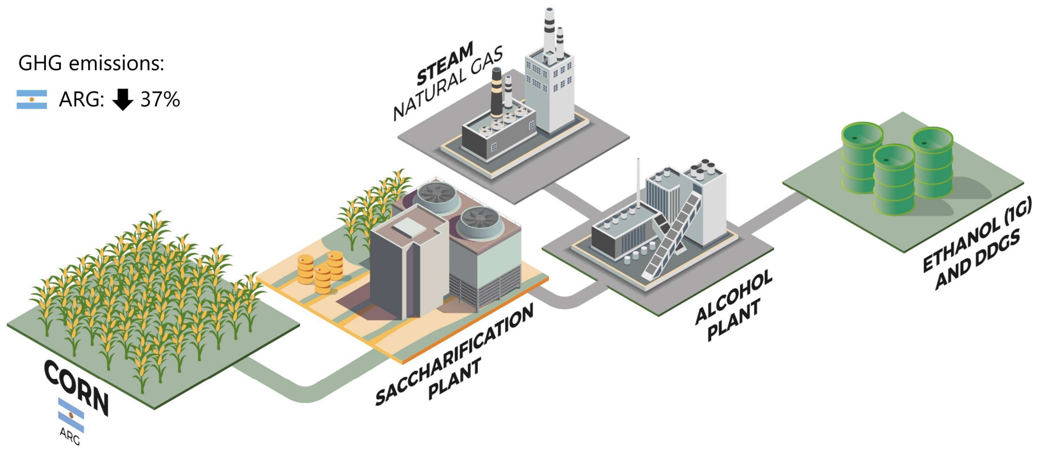


Fig. 4 - Technological routes and system boundaries for LCA and GHG emissions of ethanol in comparison to gasoline. The sugarcane ethanol supply chain and conversion processes include farming, juice extraction, sugar production, ethanol production, and combined heat and power units. Corn-based ethanol includes farming and ethanol production. The cultivation of biofuel crops includes the application of fertilizers and herbicides, harvesting, and transportation of the raw material to the mill. Sugarcane ethanol production includes chopping, cleaning, crushing to separate bagasse from juice, concentration and clarification of juice, crystallization of the juice sugar, fermentation, and distillation. Sugarcane mills are energetically self-sufficient because their required energy (electricity and steam) is sourced from bagasse via biomass boilers and cogeneration units; surplus electricity is exported to the national grid. Corn ethanol production includes grinding, liquefaction, saccharification, fermentation, and distillation. Corn ethanol plants are not energetically self-sufficient and use natural gas to supply steam and electricity. In all cases, there are food and feed co-products: sugar and distiller grain (DDGS or WDG). The arrows on the left indicate emission reductions when ethanol is compared to gasoline (ReCiPe 2016 midpoint Hierarchist method (Canabarro et al., 2023). Combined ethanol production contributed to an approximate 50 Mtonnes CO_2eq of avoided emissions.

PATHWAYS FOR BIODIESEL PRODUCTION

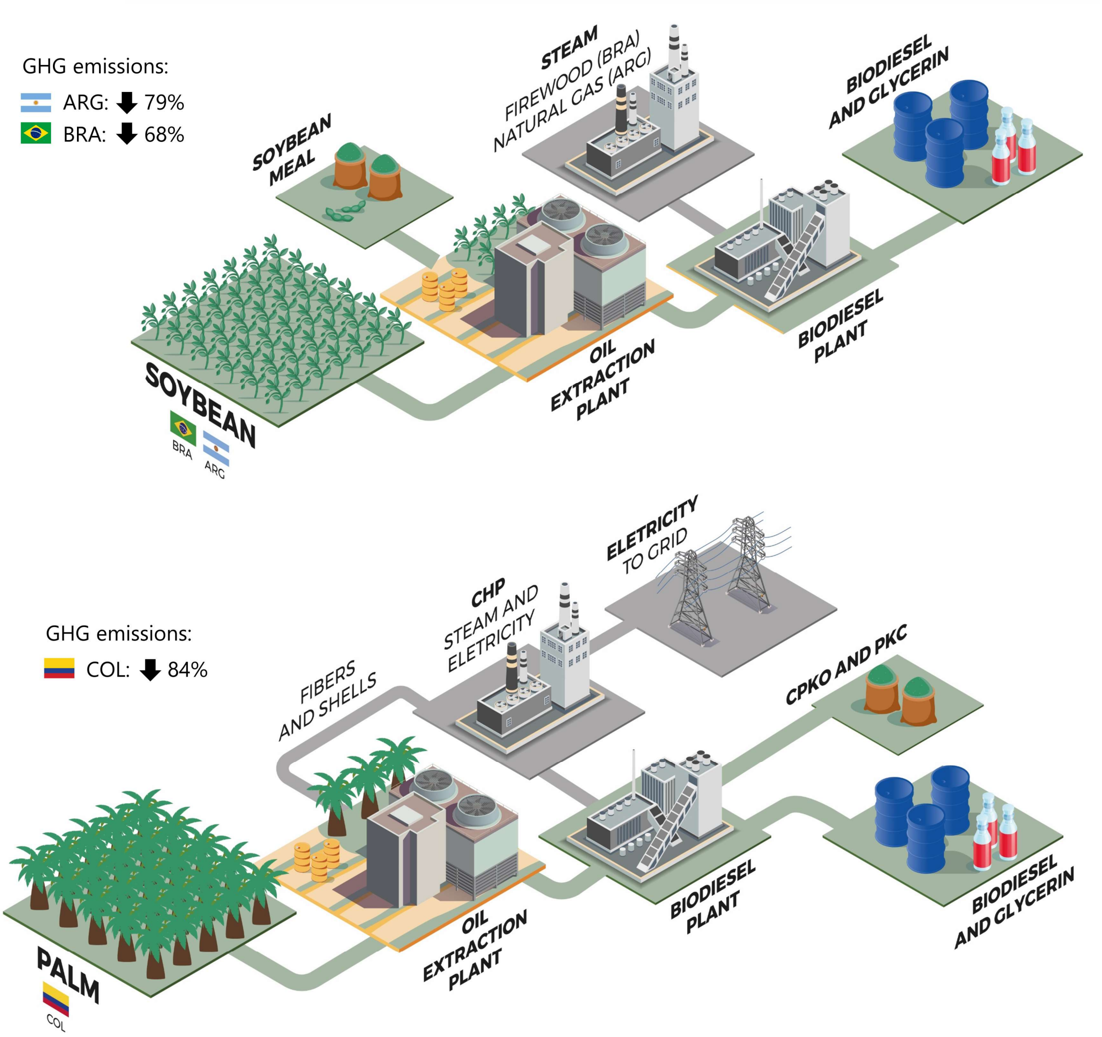


Fig. 5 - Technological routes, system boundaries for LCA and GHG emissions of biodiesel in comparison to diesel. The production of biodiesel from soybean oil and palm oil includes the following steps: farming, oil extraction, refining, and transesterification. Farming for both soybean and oil palm includes planting, growing, harvesting, and feedstock transportation. This phase uses fertilizers, herbicides, fuels, and chemicals. Soybean biodiesel plants import electricity from the grid and use heat from natural gas or forest residues and, therefore, are not energetically self-sufficient. Palm oil biodiesel plants are energetically self-sufficient because fiber and shell, both residues from the harvesting step, can be used as biomass fuel for combined heat and power units. In all cases there are food and feed co-products: meal and palm kernel cake (PKC). The arrows on the left indicate reductions in GHG emissions when biodiesel is compared to diesel (ReCiPe 2016 midpoint Hierarchist method (Canabarro et al., 2023). Combined biodiesel production contributed to an approximate 17 Mtonnes CO2eq of avoided emissions.

4. Current Land Use and Demand for Doubling of Biofuels Production

Land demand to expand biofuel production was assessed as well. Current land use data and crop yields were obtained from government reports and the Food and Agricultural Organization of the United Nations[7]. According to the results, the conversion of small portions of pastureland (from 0.1% to 10%) could add significant land to produce feedstocks to produce biofuels and allow a significant expansion of the biofuels industry. This leads us to believe that if the lands were efficiently managed and best practices used, biofuel production would not be a challenge for these countries.

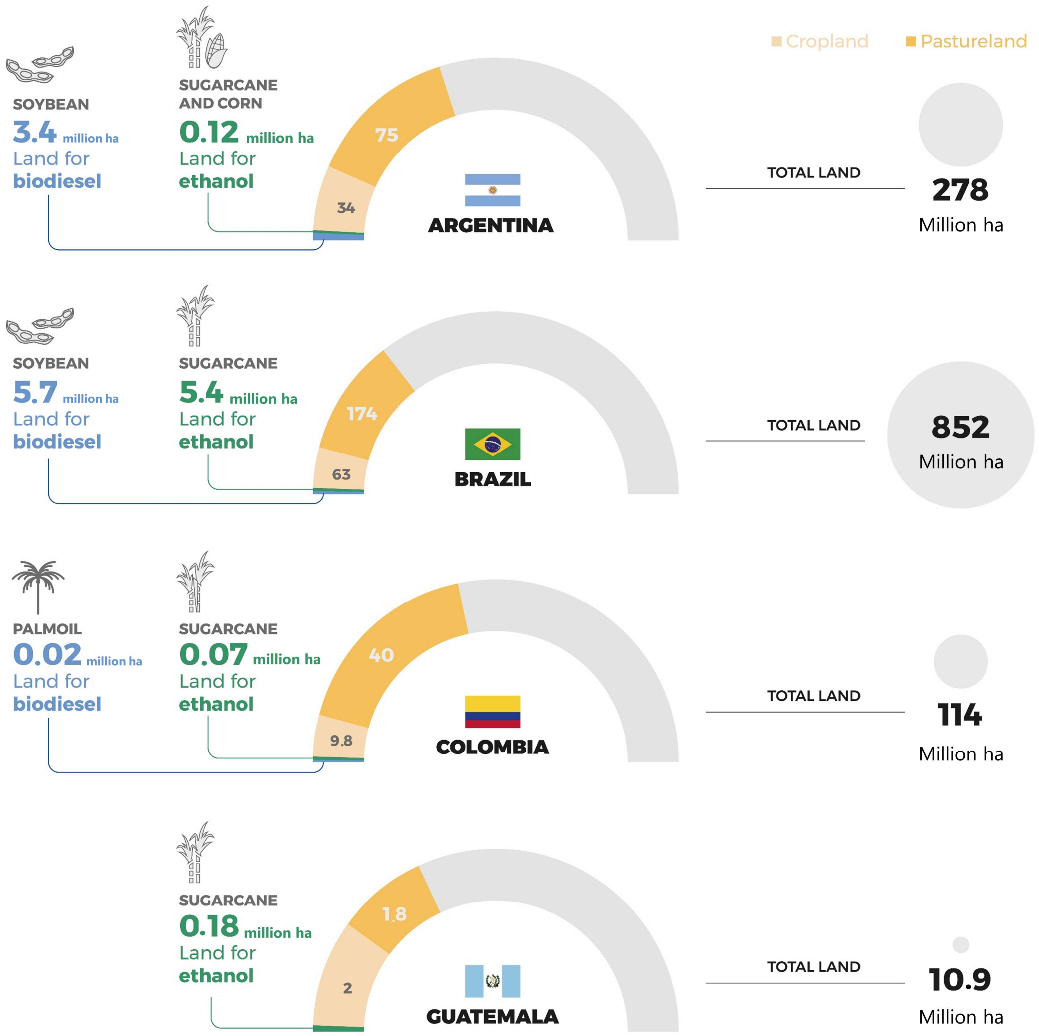


Fig. 6 - Land used for biofuels, food crops and pastures in Argentina, Brazil, Colombia, and Guatemala. Land used for bioethanol and biodiesel production corresponds to a small fraction of total land, and very little when compared to agricultural area and pastures in the four countries. The circles indicate the comparative total land sizes of the four countries.

5. BEST MANAGEMENT PRACTICES FOR LAND USE

Best Management Practices (BMP) are a system of actions associated to resource management, biomass cultivation and harvesting, waste disposal in agreement with environmental legislation, certification for markets, land management goals, conservation heritage, cultural and religious legacy, and a basic desire to meet sustainability objectives.[12] The land use and management effects of sustainable bioenergy produced from sugarcane has been recently reviewed.[13] It was observed an increased production without significant increase in crop area in recent years, which has been accompanied by the implementation of practices that decreased the use of fertilizers and water and reduced the deforestation rate in the Southeast of Brazil. Soil carbon sequestration in land-use change scenarios to expand the crop area dedicated to sugarcane expansion has been evaluated as well.

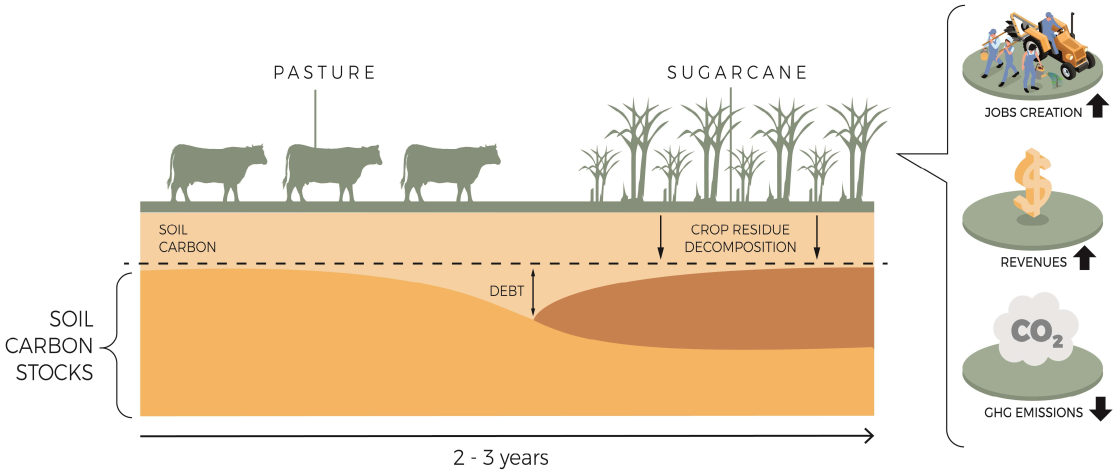


Fig. 7. Payback time for soil carbon stocks of the pasture to sugarcane transition is around 2 to 3 years. The analysis of land-use change scenarios demonstrated that, in Brazil, the conversion of approximately 3.1% of pastureland is sufficient to duplicate ethanol production, which is already a very large market. Argentina and Colombia would need to convert 0.15% and 0.2% of pastureland, respectively, to double biofuel production. Guatemala, the smallest country, would need 10% of pastures converted to be dedicated to crop land to produce raw materials for biofuels to double the volume of ethanol produced in the country. The calculation considers current yields of sugarcane, corn, soybean, and oil palm.

The effects of Land Use Changes (LUC) from sugarcane expansion on soil health and soil-related ecosystem services demonstrated positive effects, thus opening opportunities for recovery of degraded pasturelands. Best management practices include recycling of sugarcane by-products such as vinasse, filter cake and ashes with nutrient savings that promote a circular economy. Soybean cultivation requires minimum inputs for cultivation because of biological nitrogen fixation. Soybean is cultivated in sugarcane reform areas, previously recovered through a rest period, hence increasing land use efficiency and sugarcane yields in the next crop cycle.

Although about 500–900 million ha of land have been estimated to exist for rainfed production of energy crops,[14] the climate crisis has been affecting ecosystems and this reflects on the yield of crops.[15] Argentina, Colombia, and Brazil generally present good average precipitation, thus avoiding the use of irrigation to produce energy crops. Projections suggest that the south-central region of Brazil should prepare for longer droughts and heavy rains; the agricultural sector, including sugarcane, is among those with a high risk of being affected. Best management practices and breeding of crops to increase water use efficiency are recommended and under investigation by research groups in these countries. In proper climates, rainfall can cover water demand with additional water during the growing stage; however, irrigation would be recommended to achieve higher crop yields. On the industrial side, lessons have been learned over the years. For instance, sugarcane washing has been replaced by a dry-cleaning system in some mills, thus improving the evaporation process. Additionally, membranes can be used in distillation, ethanol dehydration, and concentration of vinasse. On the agricultural side, keeping straw in the field to cover the soil surface has been used to maintain soil humidity. Brazil's average water consumption in sugarcane mills has decreased fivefold in the last 30 years, from 22 m^3/t to 0.91-5 m^3/t of sugarcane. Ethanol production in Colombia has a demand of 8 m^3/t of sugarcane for the industrial side process, while the Argentinian corn-based ethanol has a demand of 11.2 m^3/t of corn. Palm oil in Colombia consumes on average 4 m^3 /t of fresh fruit bunches in the industrial processes. Soybean-based biodiesel uses 3 m^3/t of soybean.

The evolution of decarbonizing light vehicle transportation in Brazil [16,17]

Ethanol has been in use in transportation in Brazil for almost a century. In 2003, the flex-fuel vehicle technology was implemented in full scale, and that allowed consumers to choose between gasoline and ethanol according to preference and, importantly, fuel prices. In 2010, hybrid gasoline vehicles were made available as well and, a decade later, hybrid ethanol vehicles followed. Electric vehicles are also now available, but flex fuel engines continue to compose most of the new fleet because of the prices of electric vehicles. Solar and wind power are growing to provide electricity, but bioenergy is an increasingly important option in the energy transition as it can provide fuels with a high energy density that can be stored, fit in the present infrastructure of refueling stations and vehicle manufacturing, and provide building molecules for different uses.

Flex-fuel technology has been an enabler of biofuels end use in Brazil. This technology contributed to decreased pollution in cities and continues to be a sustainable alternative in the Brazilian context. Fleet sustainability needs to consider aspects that go beyond GHG emissions including economic feasibility. Incentives focusing on the reduction of GHG emissions through transport electrification may overload the electric grid because infrastructure might not be sufficient to supply the domestic demand and an electric vehicle fleet in some developing countries. Electric and hybrid cars raise economic concerns related to acquisition costs and lifespan with higher depreciation rates than flex-fuel vehicles. Electric and hybrid cars also present environmental concerns related to battery manufacturing (mostly mining processes) and recyclability. Despite this not being the case of Brazil, the use of fossil resources such as lignite in the electricity mix of other countries undermine the environmental benefits of electric cars. Innovation is gearing recently towards hydrogen produced on board using ethanol (Fuel Cell Electric Vehicles). Solid oxide fuel cells (SOFC) seem to be an interesting alternative since they combine the advantages of biofuels as renewable energy carriers and the high energy efficiency of electric vehicles. The use of SOFC could improve autonomy, reduce GHG emissions, and benefit from currently existing refueling infrastructure.

6. Conclusions

- Biofuels production in Argentina, Brazil, Colombia and Guatemala is energetically sustainable and contributes to significant reductions in GHG emissions.
- Currently, biomass crops for biofuel production uses 14.9 Mha of land in these countries and if 5% of their pasturelands is converted to increase biomass crop area, biofuels production could double.
- Farming activities and natural gas use in processes are responsible for the most significant contribution to GHG emissions (70%) in biofuel production.
- A low carbon intensity biofuels policy framework could be considered to stimulate biofuel production and reward the current low carbon energy effort that is reducing 63.8 MtonCO_2eq per year.
- Ethanol and biodiesel are economically viable in all cases, and highly sensitive to feedstock prices.

7. Recommendations

- Higher feedstock yields have large impacts on emissions and can alleviate land demand; therefore, efforts on research focused on feedstock development and greening of farming should be intensified.
- Portfolio diversification and new business models in the sugar and biofuel sectors (biogas, carbon capture and use, and hexose/pentose sugar uses for bioproducts) can stimulate innovation and economic robustness of this industry sector.
- The sugarcane ethanol plants of these four countries could be exporting 25.9 TWh of electricity to the grid; therefore, investments to increase energy efficiency should be considered.
- Ethanol plants that already have cogeneration units could increase the use of lignocellulosic materials (straw and energy cane) considering their on-site availability to increase use efficiency, income and reduce emissions.
- Green hydrogen on board produced from ethanol may be an interesting alternative to vehicle electrification using the existing refueling infrastructure.

8. Acknowledgments

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