

Article

The Role of Small-Scale Biofuel Production in Brazil: Lessons for Developing Countries

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Abstract: Small-scale biofuel initiatives to produce sugarcane ethanol are claimed to be a sustainable opportunity for ethanol supply, particularly for regions with price-restricted or no access to modern biofuels, such as communities located far from the large ethanol production centers in Brazil and family-farm communities in Sub-Saharan Africa, respectively. However, smallholders often struggle to achieve economic sustainability with ethanol microdistilleries. The aim of this paper is to provide an assessment of the challenges faced by small-scale bioenergy initiatives and discuss the conditions that would potentially make these initiatives economically feasible. Ethanol microdistilleries were assessed through a critical discussion of existent models and through an economic analysis of different sugarcane ethanol production models. The technical-economic analysis showed that the lack of competitiveness against large-scale ethanol distillery, largely due to both low crop productivity and process efficiency, makes it unlikely that small-scale distilleries can compete in the national/international ethanol market without governmental policies and subsidies. Nevertheless, small-scale projects intended for local supply and integrated food–fuel systems seem to be an interesting alternative that can potentially make ethanol production in small farms viable as well as increase food security and project sustainability particularly for local communities in developing countries.

Keywords: bioethanol; sugarcane; microdistilleries; food–fuel systems

1. Introduction

Over 2 billion people in developing countries still rely on traditional biomass for energy (cooking and heating) which causes 1.5 million deaths a year as a result of smoke inhalation [1]. Moreover, it has been estimated that 1.6 billion people have no access to electricity [2]. Therefore, improving local access to safe and efficient forms of energy is essential to achieve the “Sustainable Development Goals (SDGs)”, a set of universal goals supported by the United Nations to improve global life quality and sustainability [1,2].

Many developing countries such as Brazil and Sub-Sahara African countries hold the potential to produce bioenergy in many forms such as biogas [3–5], biodiesel and bioethanol [6,7] due to favorable conditions as an existent agriculture-based system, favorable climate for a variety of feedstock production, and land availability [6,8]. However, producing bioenergy at the same time as ensuring

social benefits is challenging and requires pro-poor policies and strict regulations to avoid negative social impacts such as food instability, unrestricted change in land use, and deforestation [9].

Small-scale bioenergy projects such as microdistilleries have been acknowledged as a sustainable way for rural communities to access affordable energy services [7]. Moreover, small-scale biofuel initiatives are, in many cases, believed to be the only model for developing countries to meet biofuel targets such as in (non)mandatory blending policies, while defraying environmental impacts and promoting economic development through the creation of job opportunities, particularly in rural areas [10,11]. Despite promising features, the potential of small-scale biofuel initiatives to make a significant energy contribution while honoring other priorities such as sustainability and food security seems yet far from fully achieving its targets. Small-scale initiatives as a business model have only a marginal contribution to global biofuel production, led by large scales in the US and Brazil [12,13]. In addition, the once-clear socioeconomic and environmental benefits of small over large projects become increasingly blurred due to economic viability, change in land use, and concerns about food security [7,14]. Furthermore, the amount of scientific information on the different aspects associated with biofuel production, particularly on a small scale, remains limited [15,16] and more information, not only on the economics aspects but also on the social challenges and opportunities for local particularities, are needed. Undoubtedly, policymakers, development practitioners and other stakeholders can benefit from new and insightful knowledge as to the opportunities and limitations of small-scale biofuel production, especially in developing regions such as Brazil and Sub-Saharan Africa due to the already existent sugarcane production and the available information in these countries (e.g., [17]).

Although few studies have been published indicating economic feasibility of small-scale distilleries [18,19], they usually present analysis based on optimistic scenarios and sometimes idealistic, non-real-world data. For instance, [20] presented an economic analysis of ethanol production in an already existent *cachaça* (a Brazilian spirit) production facility. Therefore, he did not consider essential initial costs with building and infrastructure [20]. In another example, [19] also presented a successful economic analysis of ethanol-*cachaça* production. However, for their analysis they considered a cooperative system in which several small farms produce ethanol in a central microdistillery unit. This is a system that has been discussed as possibly beneficial [11,19] but had not yet been successful due to management challenges, lack of technical knowledge and transportation logistics and costs from each farm to the central units [11,16]. Moreover, the lack of successful small-scale distillery cases supports the need for a more comprehensive analysis. Therefore, our main objective in this paper is to gain useful knowledge on the social-economic rationality of small-scale biofuel initiatives and to identify main opportunities and shortcomings.

We aim to shed light on the socioeconomic and environmental impacts of biofuel production by comparing average large-scale with “alternative” small-scale initiatives and to understand if and in which circumstances small-scale bioenergy production could work. Therefore, a technical-economic analysis was performed comparing different biofuel production scenarios in order to understand the challenges and opportunities faced by small-scale production.

Our analysis focuses on sugarcane ethanol in Brazil due to the availability of information and accumulated experience regarding both large- and small-scale projects, a rather unique characteristic among developing regions. We use complementary information from other regions, such as Southern Africa, to increase and expand the impact our discussion and conclusions.

2. The Brazilian Small-Scale Experience

In Brazil, the threshold between small and large was defined by law in 1981 at 5000 L day⁻¹ capacity for ethanol projects [21]. The scale component in biofuel production can be associated with both the agricultural (feedstock production) or industrial (processing activities) phases. The scale is also associated with the adopted technology level. Large-scale biofuel initiatives are coupled with several options for mechanized activities and process automation, updated and efficient technology

and skilled labor. Under small-scale, feedstock production is predominantly relying on manpower, while the processing unit is modest or out-of-date, with limited technology choices. In our approach, small-scale projects are defined by the processing phase of the biofuel value chain, in which a limited number of production systems (i.e., feedstock production variants) are associated.

A common characteristic among national and regional governments in pursuing small-scale biofuel projects is the belief that this design is the best model to meet local/regional energy supply while complying with environmental and socioeconomic sustainability criteria. Although some scholars support this view [10,11], recent evidence has shown that community-based biofuel production is not always the best solution [22] and cases of success are rare. Brazil's first glance at small-scale production of ethanol (microdistilleries) was in 1981 with the introduction of the first legal framework for microdistilleries. A study developed by the Policy Innovation Systems for Clean Energy (PISCES) (2009) in collaboration with the Food and Agriculture Organization (FAO) described a number of small-scale biofuel initiatives in twelve different countries in Latin America, Africa and Asia. In most of the explored regions there is a substantial reliance on solid fuels (i.e., firewood and coal), particularly for cooking in Africa and Southern Asia. Therefore, 60% of the biofuel cases were designed to serve household energy needs. Other uses include mobility (e.g., ethanol fuel) and services such as water pumping and street lighting [7]. In countries such as China, efforts towards energy access in rural areas through small-scale projects led the construction of over 400 village-level biogas stations in the Shandong province aimed at providing a sustainable and affordable modern energy supply to poor smallholders [22].

Despite the interest in fostering ethanol production, the development of microdistilleries stumbled over many obstacles, from lack of skilled labor, inherent inefficiencies in different parts of the processing phase and, maybe more important, lack of economic competitiveness. Over the years, large-scale projects (capable of processing one million liters of ethanol per day or more) based on increased use of technology, in the agricultural and industrial phases, became the standard ethanol production model across the country [23]. Although limited, microdistilleries persist in the form of dedicated biofuel agro-industries or multi-purpose units from which ethanol is one in an array of different agro-processed products [11].

Ethanol-dedicated microdistilleries are concentrated in the South of Brazil. This region offers a niche market for ethanol under small scale due to the relatively higher prices of ethanol (up to 40% more expensive) than in the Southeast region where the state of São Paulo, the largest producer of sugarcane in the country [24], functions as a distribution hub to other regions of the country. Multi-purpose microdistilleries, on the other hand, are more scattered across country being often associated with *cachaça* production. Minas Gerais, because of its tradition as a *cachaça*-producing region combined with R & D efforts to implement viable farm-level fermentation and distillation technologies, has a leading role in the production of ethanol in multi-purpose settings [25]. Together with *cachaça* and ethanol, multi-purpose distilleries can also combine other sugarcane-based food products such as *rapadura* (non-centrifugal sugar like *panela* in Colombia and *gur* in India), brown sugar and molasses [16].

Ethanol has been present in Brazil since the 1920s, but its official debut occurred with the creation of the ProAlcool program in 1975 [26]. The legal framework for microdistilleries came some time later, with the Decree 85,698 of 1981 [21] and a key aspect of this decree is that ethanol produced by microdistilleries should be exclusively destined to self-consumption. This condition associated with the limited availability of public funds were important hindering factors to the development of microdistilleries as it limits profits, making it an uninteresting business [27]. Although commercialization at the national level remains under debate, over the last decades states such as São Paulo, Minas Gerais and Rio de Janeiro have implemented regional legislation to foster microdistilleries through their inclusion in development programs, with facilitated access to funding and credit. However, there are no available data on the results of these initiatives.

Local particularities in terms of economy, legislation and environmental parameters significantly affect the inclusion and success of ethanol microdistilleries around the developing world. For instance, Brazilian current ethanol structure based on large-scale production and its legislation for safety, quality assurance and commercialization opens little room for the development of ethanol production by smallholders, particularly for the transportation market in São Paulo State, which is the main ethanol-producing State in Brazil [16]. However, differently from São Paulo State (SP), in the Rio Grande do Sul State (RS), the predominance of mountainous topography and the existence of a large number of smallholders in family agriculture make it more feasible for ethanol microdistilleries implementation [28]. Moreover, the distance from the main production center in SP makes ethanol in RS one of the most expensive in Brazil (US\$1.22/L against US\$0.79/L in SP, in January 2017).

Using Brazilian lessons and experience, we discuss the particularities of bioenergy in developing countries in Africa as they possess an existent sugarcane production system that could be a starting point for biofuel production. In Sub-Saharan African countries such as Mozambique, challenges for the implementation of microdistilleries include the economy that relies on the exclusive importation of fossil fuels, the lack of infrastructure for biofuel distribution, and the lack of technical labor [7,29]. Therefore, microdistilleries projects for national supply are significantly challenging. Nevertheless, microdistilleries to support self-consumption or to attend local communities are more realistic in a near future. Moreover, small-scale bioethanol production linked to food production has a high potential to contribute to rural development in poor regions [28].

3. Methodological Approach

To explore the economic feasibility of microdistilleries, we compared a standard ethanol-dedicated scenario with alternative scenarios. Apart from ethanol, two common products from microdistilleries in Brazil and other developing regions are ethanol spirits (e.g., *cachaça* in Brazil) and brown sugar. The scenarios considered in this study are described below:

- (1) *Ethanol microdistillery*—Scenario 1 (benchmark) is an ethanol-dedicated microdistillery with a processing capacity of 1000 L of ethanol (92% *v/v*)/day. In this scenario, smallholders clustered around the microdistillery to supply the industrial plant with sugarcane. This model aims at regional supply of transport fuel, particularly among local farmers, through ethanol production and collective action initiatives (i.e., cooperatives or farmer's associations);
- (2) *Cachaça microdistillery*—Scenario 2 is a *cachaça*-dedicated microdistillery with a production capacity of 53 L of *cachaça* (45% ethanol *v/v*) per day. Instead of community-based, such as in Scenario 1, this scenario introduces a household production model. This scenario is common in some regions of Brazil, such as the States of Minas Gerais and São Paulo, where family farms cultivate and process sugarcane and sell *cachaça* as a source of family income;
- (3) *Cachaça and ethanol microdistillery*—Scenario 3 is the same as Scenario 2 with the addition of the production of 6 L of ethanol per day from *cachaça* waste (waste alcoholic streams from *cachaça* distillation, unsuitable for consumption);
- (4) *Brown sugar*—Scenario 4 considers the production of brown sugar. In this scenario, instead of ethanol (i.e., fuel) and *cachaça*, sugarcane production is destined to food production, as brown sugar, which finds informal and formal markets in both rural and urban areas.

Scenario 1 requires relatively high financial investments in the agricultural (sugarcane production) and industrial phases. Moreover, it presents management challenges to the smallholders, who have poor access to credit and are often limited by technical knowledge. However, if feasible, this scenario could supply regional ethanol markets through the decentralization of fuel production and distribution, with economic benefits for consumers and smallholder farmers. On the other hand, scenarios 2–4 account for farm-level production of sugarcane products (i.e., *cachaça*; *cachaça* + ethanol; brown sugar), produced in relatively small quantities and aimed at local markets. Our approach, therefore, proposes two general views over small-scale production of ethanol in developing countries. The first (Scenario 1)

explores the economic feasibility of ethanol-dedicated microdistilleries, designed to attend to regional energy demands and strengthen biofuel production while offering an income opportunity for local farmers. The second (Scenarios 2–4) explores farm-level economic opportunities associated with sugarcane products, i.e., *cachaça*, ethanol and brown sugar, for both farm self-sufficiency (ethanol) and local markets (*cachaça* and brown sugar).

Table 1 presents a summary of the scenarios and technical coefficients. The combination of scenarios and sugarcane yield levels amounted to eight simulations.

Table 1. Scenarios for microdistilleries in Brazil.

Description		Sugarcane Yield Levels (t/ha)		Production Yield (L or kg/t Sugarcane)
1	Ethanol microdistillery	40	80	55
2	<i>Cachaça</i> microdistillery	40	80	97 ^a
3	<i>Cachaça</i> + ethanol microdistillery	40	80	97 + 11 ^a
4	Brown sugar	40	80	110 ^b

^a Average values from 2 Brazilian *cachaça* microdistilleries. Source: [30,31]; ^b Source: [32].

The variables used for the evaluation of scenarios were divided into two groups: agricultural and processing stage. In the agricultural stage, sugarcane yield level is a key parameter because it significantly affects the economic feasibility of biofuel projects. For instance, several biofuel projects implemented in Sub-Saharan Africa failed largely due to unrealistic prediction of feedstock productivity [29]. Therefore, we assumed two yield levels: 40 and 80 t sugarcane per hectare. The former reflects locations usually found in developing countries, presenting restricted or no irrigation, low nutrients/fertilizers inputs, less suitable topography, etc.; while the latter is an average productivity in the Center-South region in Brazil [33], which requires more inputs, technology, adequate sugarcane varieties, proper management and results in lower final cost of sugarcane.

The Virtual Biorefinery (VBS) tool and its databases were used to simulate Scenario 1 (Ethanol microdistillery) [34]. VBS is a framework to assess technical, environmental, economic and social impacts of bioenergy projects in Brazil. Alternative scenarios, i.e., Scenarios 2–4, that consider other products were simulated with the support of VBS, but using complementary information collected during fieldwork, literature review (referenced throughout the text) and experts' consultation from the Brazilian Bioethanol Science and Technology Laboratory (CTBE). Moreover, equipment costs were estimated from Brazilian suppliers. It was also assumed that there was stable access to electricity and fuel (e.g., coal or fuelwood), although we acknowledge that access to energy sources may be challenging when operating processing facilities in remote communities.

Apart from literature review and experts' consultation, the database was complemented with primary data collected among microdistilleries in southern Brazil (state of Rio Grande do Sul). Over the last years, the state of Rio Grande do Sul (RS) has been a hub for R & D developments around microdistilleries. Being relatively far from traditional sugarcane-producing regions, which is mainly in the Center-South region, ethanol in RS is among the most expensive in Brazil. High prices for ethanol have attracted a number of initiatives to boost local and decentralized ethanol production, often through microdistilleries. In July 2014, we visited and interviewed the president and the manager from a biofuel cooperative in the municipality of Frederico Westphalen (RS), a local smallholder sugarcane producer and an extension agent that gives technical support to sugarcane producers in the region. The manager of a microdistillery facility manufacturer in the state capital Porto Alegre was also interviewed. A semi-structured questionnaire guided the interviews. All data collected served to fine-tune the parameters used to design the different scenarios explored in this work, which includes crop yield levels, processing efficiencies, ethanol prices, alternative products to ethanol-dedicated microdistilleries and investment costs.

Tables 2 and 3 show the operating parameters and initial investment for the evaluated scenarios. Scenario 1, which is an ethanol-dedicated microdistillery (1000 L/day), requires higher equipment investment than in other scenarios due to its larger industrial processing capacity (Table 3). Building and infrastructure costs in scenarios 2–4 were estimated based on equipment costs and construction area.

Table 2. Operational parameters assumptions for the evaluated scenarios.

Parameters	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Unit
Biomass processing	3000	120	120	120	tons of sugarcane (TC)
Maintenance	3%	3%	3%	3%	of fixed capital investment
Labor	3	1	1	1	people
Electricity consumption	68.5	68.5	68.5	72.6	kWh/TC
Yeast consumption	0.71	0.71	0.71	-	kg/TC
Wood consumption	0.4	0.26	0.34	0.69	m ³ /TC
Bottles	-	11,640	11,640	-	I = unit of 1 L glass bottle
Package	-	-	-	13,200	unit of 1 kg sugar package
Selling price	0.61 ^b	1.22 ^a	1.22 ^a / 0.61 (<i>cachaça</i> /ethanol)	1.38	US\$/L or US\$/kg

^a Average price of 1 L *cachaça*. Source: [35]; ^b Average ethanol price received by small-scale producers in Rio Grande do Sul State.

Cash flow analysis of the four scenarios considered a 20-year project lifetime; prices and operating costs were based on values from December 2016. The biomass production costs were calculated in CanaSoft model, a biomass calculator model built into the Virtual Sugarcane Biorefinery framework [34], considering sugarcane yield levels of 40 or 80 t of sugarcane per hectare. It was also assumed that sugarcane products (ethanol, *cachaça* and brown sugar) will be sold at market prices (Table 2). Monetary conversion from Brazilian Real to Dollar was made using the average conversion value between June and December 2016 (about R\$3.27 = US\$1.00).

Table 3. Investment costs for the evaluated scenarios.

Investment	Scenario			
	1	2	3	4
Building and infrastructure (US\$)	18,352 ^a	1606	1655	8781
Equipment (US\$) ^b	60,717	5744	6050	29,021
Working capital	7907	735	770	3779
Total (US\$)	86,975	8088	8475	41,572

^a Source: [11]; ^b Based on Brazilian suppliers.

The economic feasibility of the different scenarios was assessed through Internal Rate of Return (IRR) and Net Present Value (NPV). The analysis was complemented by sensitivity analyses in terms of interest rate and ethanol market price.

4. Results

In order to assess the economic feasibility of the different small-scale scenarios, the NPV was used for comparison (Figures 1 and 2). The discount rate initially assumed in this study was 12% per year, which represents the average value for the sugarcane industry in Brazil. However, in the case of small family farms, 12% is a rather impractical value; therefore, values varying from 4 to 12% per year were evaluated [11].

According to the economic analysis represented by the cash flow in Figures 1A and 2A, Scenarios 1 did not reach a positive net present value in any of the cases, indicating that the projects are not economically attractive under the assumptions considered in this study. The operating costs and the cost of investment in these scenarios exceeded the revenues, thus generating negative net cash flows.

Figures 1B and 2B show the NPV for scenarios 2–4 for the two sugarcane productivities considered in this study (40 and 80 t sugarcane/ha, respectively). It can be seen that only Scenario 4 would be

a feasible alternative considering both the sugarcane yield levels and the economic assumptions in this study. These results indicate that average brown sugar price (US\$1.38 per kg) is related to positive margins and pays off the investment and operating costs even considering a 12% discount rate. For Scenarios 2 and 3, only the alternative considering higher sugarcane yields resulted in economically feasible scenarios.

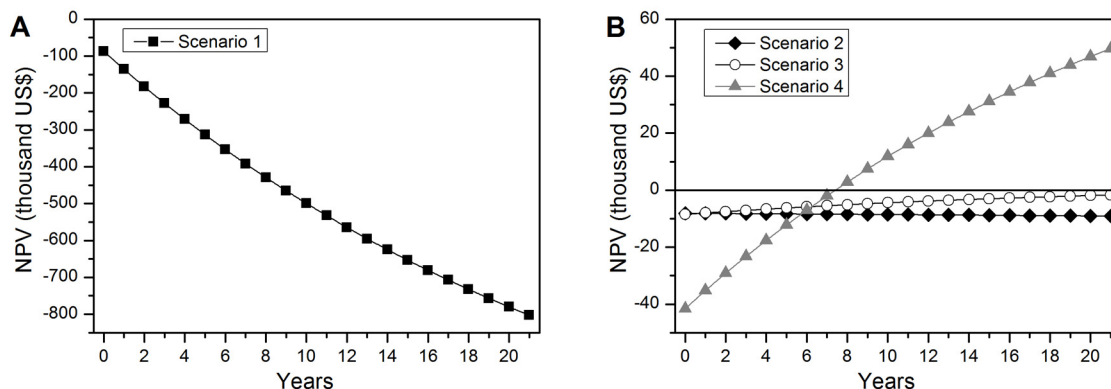


Figure 1. Net Present Value (NPV) for scenarios: (A) 1 and (B) 2, 3 and 4, considering a discount rate of 4% and sugarcane yield at 40 t per hectare.

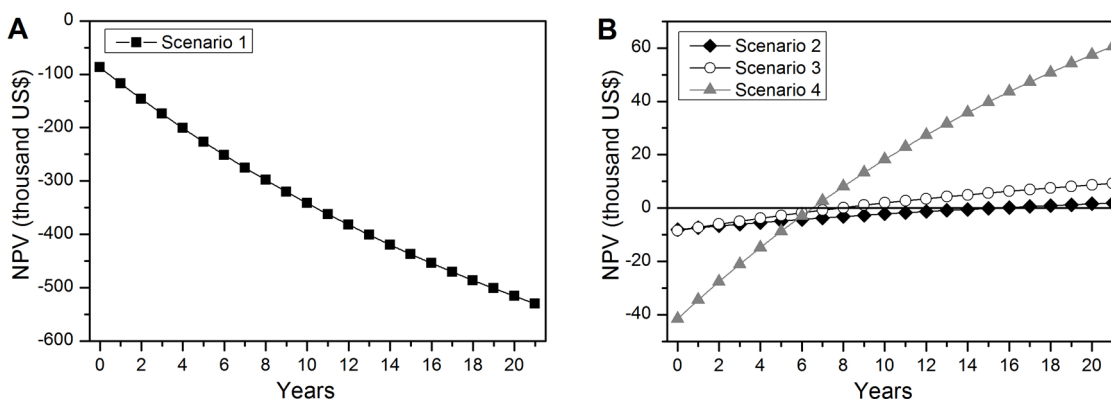


Figure 2. Net Present Value (NPV) for scenarios: (A) 1 and (B) 2, 3 and 4, considering a discount rate of 4% and sugarcane yield at 80 t per hectare.

Table 4 shows all the NPV for the scenarios and the associated market prices for the products that would make the project economically feasible considering both sugarcane yields and the discount rate.

Considering these results, it is possible to infer that Scenario 1 (ethanol-dedicated distillery) is not likely to be feasible even considering current ethanol selling prices at fuel stations as a reference market price (around US\$1.22/L in Rio Grande do Sul). That is because the price paid to the producer (in this case the farmer) is significantly lower than the filling station due to taxes, transportation costs and distributor margin. On the other hand, Scenarios 2 and 3 would be economically attractive in some of the cases, for instance, with higher sugarcane yields. Moreover, the production of ethanol in the *cachaça* microdistillery was decisive for economic feasibility at discount rates of 12 and 8%. In fact, the economics of these scenarios could be even improved considering that high-quality *cachaça* can achieve internal market prices ranging from US\$0.92 to US\$5.51 per bottle [36]. Finally, under the considerations taken in this evaluation, Scenario 4 was shown to be economically feasible in all cases considering both the sugarcane yield levels and the discount rates, which was somehow already expected since sugar has a higher relative market price compared to ethanol.

Table 4 also illustrates that economic feasibility can be highly dependent on sugarcane productivity per hectare. Mayer [28] evaluated the feasibility of a small-scale distillery (720 L/day) and analyzed two possible scenarios: (1) selling fuel to cooperative members; (2) commercializing fuel. Depending on the cost of feedstock, both scenarios resulted as being economically unfeasible. However, when the cost of feedstock was lower due to high productivity, the first scenario can be attractive in economic terms [28]. Thus, a reliable yield estimate is of paramount importance when designing a microdistillery facility in order to properly predict its economic feasibility.

Several authors have already stated that the formation of cooperatives that bring smallholders together is a way of achieving the economies of scale [11,16,19]; however, the lack of infrastructure, management challenges, production logistics and distance to the distribution centers are difficulties to be overcome and successful cooperatives for this purpose are still to be proved.

From the results and the lack of successful ethanol-dedicated microdistillery cases, it is possible to infer that due to the lack of economic sustainability, microdistilleries require a more complex production model and significant subsidies in order to become economically competitive considering the traditional ethanol-exclusive production presented. In this way, as it is demonstrated by the economic results, the addition of other products, particularly the ones with higher relative added value could be crucial for the economic viability of small distilleries.

Table 4. Economic assessment results.

	Ethanol		Cachaça		Cachaça + Ethanol		Brown Sugar	
	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Discount rate (% per year)	12%							
Productivity (TC/ha)	40	80	40	80	40	80	40	80
NPV (US\$)	(475,354)	(325,254)	(8554)	(2673)	(4753)	1129	7902	13,783
Minimum ethanol selling price	1.01	0.89	-	-	-	-	-	-
Minimum <i>cachaça</i> selling price	-	-	1.33	1.26	1.28	-	-	-
Discount rate (% per year)	8%							
Productivity (TC/ha)	40	80	40	80	40	80	40	80
NPV (US\$)	(597,714)	(402,939)	(8737)	(946)	(3577)	4214	23,802	31,593
Minimum ethanol selling price *	0.99	0.87	-	-	-	-	-	-
Minimum <i>cachaça</i> selling price	-	-	1.30	1.23	1.26	-	-	-
Discount rate (% per year)	4%							
Productivity (TC/ha)	40	80	40	80	40	80	40	80
NPV (US\$)	(802,853)	(530,059)	(9049)	1863	(1669)	9215	49,722	60,634
Minimum ethanol selling price *	0.98	0.85	-	-	-	-	-	-
Minimum <i>cachaça</i> selling price	-	-	1.28	-	1.24	-	-	-
Internal rate of return (% per year)	n.a. **	n.a. **	n.a. **	6.1%	1.3%	13.9%	14.8%	16.9%

* Price paid to the producer (no taxes); ** Internal rates of return were not calculated since the supplier cash flow array did not contain at least one negative and at least one positive value.

It should be noticed that it is unlikely that microdistilleries will have a significant production impact countrywide, unless higher selling prices (of both ethanol and cachaça) are achieved under specific conditions of local or even external markets, in the case of cachaça. Using the Brazilian case as an example, 500 microdistilleries (1000 L/day) would only contribute to 0.4% of the total ethanol produced annually in the country. Therefore, rather than a solution to an entire country, the advantages of microdistilleries are concentrated to local socioeconomic improvement such as an increase in profit and energy supply for self-consumption in small villages/communities [37]. Furthermore, local environmental benefits have also been often associated with small-scale distilleries due to lower use of mechanized harvesting (which reduces soil compaction and diesel use), low biodiversity losses and less use of water supply due to rotation of crop usually applied in small farms, and a potential decrease in CO₂ emissions during ethanol production chain due to local ethanol end-use, which decreases CO₂ emissions during transportation for fuel distribution and may increase the sustainability of the project [11].

5. Discussion: Challenges and Opportunities of Microdistilleries in Brazil and Developing Countries

One of the main reasons why ethanol from microdistilleries is not cost-competitive compared to large-scale production is low efficiency in several steps of the production process, besides the impacts of economies of scale in the investment and operating costs. In the agricultural sector, the main efficiency difference between small and large scale is due to sugarcane harvesting as in the former it is usually made manually, while in the latter the mechanized harvesting can lead to slightly higher efficiency and lower costs [11]. In the processing sector, losses and inherent inefficiencies in all unit operations compromise the global process efficiency. For instance, the percentage of sugar that remains in the bagasse in the milling step decreases ethanol productivity per ton of sugarcane; fermentation contamination caused by poor control results in raw material losses; and low thermal efficiencies during distillation causes ethanol losses in the vinasse [28], all of which contribute to compromising the economic feasibility of microdistilleries.

In addition, production of electricity as a by-product in ethanol distilleries is done almost exclusively in large-scale industries and it is a significant contribution to the economic feasibility in most of the cases in Brazil. Apart from being self-sufficient, ethanol distilleries can sell surplus electricity to the national grid [28]. Therefore, the challenges faced by microdistilleries result in an increase in the ethanol production cost and, consequently, it seems unrealistic that without large subsidies this model of production will ever compete with ethanol produced in large-scale industries.

Nevertheless, in locations far from the ethanol production centers such as Rio Grande do Sul State in which the ethanol price makes it a very expensive fuel, microdistilleries, particularly the ones that are not ethanol-exclusive, have a potential to be both economically viable and socially beneficial mainly when ethanol and other products are not targeting large consumer markets.

Using the Brazilian experience and challenges as well as the results from the economic analysis, we could draw some lines about the potential of these lessons in some developing countries. In low-income regions, such as the Sub-Saharan African countries, the production of ethanol for self-consumption and/or to local communities is particularly interesting as the access to modern fuel for cooking and electricity is reduced [16]. Therefore, the inclusion of small-scale distilleries in these communities could be of great importance to improving life quality and pursuing sustainable fuel production as supported in the SDGs. Although the use of ethanol for household devices (cooking, lamps) face some challenges such as cultural resistance and need for amenable equipment (e.g., ethanol stove), ethanol production by family farmers has the potential to increase life quality in certain regions [16]. Moreover, the integration of sugarcane production with other farm activities such as livestock and other food crops might be the most promising way of achieving economic feasibility [28,38].

The utilization of by-products from ethanol/*cachaça* distilleries could also increase smallholder's revenue. By-products such as vinasse and bagasse could help in achieving economic viability of small-scale distilleries if they are integrated into other local agricultural systems or if they could be sold as fertilizers and animal feed or even exchanged for firewood. Nevertheless, the cost of the techniques required for the utilization of these by-products, as well as the lack of trained people and logistic problems, are challenges faced by smallholders [28].

In conclusion, although it is theoretically possible to replicate and transfer some Brazilian microdistillery models for production of fuel and food to certain regions of Sub-Saharan Africa, there are several challenges to consider in order to make these projects successful and sustainable in the long run. Access to electricity for processes such as milling, as well as cultural adaptation to the use of ethanol as cooking fuel, are important issues to be considered [16]. Moreover, government policies would be of extreme importance if the project aims at a regional rather than a local development as both infrastructure and subsidies would become critical.

6. Conclusions

Small-scale ethanol distilleries are commonly considered for national supply; however, they frequently lack price-competitiveness compared to large-scale production. The economic analysis presented in this work showed that ethanol-exclusive microdistilleries are not likely to be feasible taking into consideration the current ethanol policy and common market scenarios in Brazil. However, the analysis showed that other higher value sugarcane products such as *cachaça* and brown sugar integrated with ethanol production could be an economically viable scenario, especially if markets with higher willingness-to-pay—such as the external markets—are reached. In addition, product diversity in small-scale projects could increase biofuel access as well as food security and sustainability. Using the Brazilian experience and the analysis performed in this work, the potential of microdistilleries in developing countries such as Sub-Saharan Africa was discussed and challenges and opportunities were presented. In conclusion, a change in the common ethanol distribution concept from national to local scenario as well as product diversification is of significant social importance and could be decisive for the economic feasibility of microdistilleries.

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