CHEMICAL ENGINEERING TRANSACTIONS

VOL. 37, 2014

A publication of AIDIC

The Italian Association of Chemical Engineering
www.aidic.it/cet

Guest Editors: Eliseo Ranzi, Katharina Kohse- Höinghaus

ISBN 978-88-95608-28-0; ISSN 2283-9216

DOI: 10.3303/CET1437140

The Sustainability of Sugarcane Ethanol: The Impacts of the Production Model

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Ethanol is the main biofuel produced and used today, representing almost 80 % of the total liquid biofuels production and use worldwide. Sugarcane is now the second most used feedstock, behind corn, but it is the one that presents the best performance in terms of GHG emissions reduction and land demand, and it is also a crop more adequate to developing countries production as it is cultivated already in more than 100 countries. The fast expansion of bioethanol in the recent past has brought to light several concerns about its sustainability and the discussions have been, mostly, in generic terms and with strong bias especially toward social aspects. It must be born in mind that biofuels are not equal and even the same biofuel, ethanol in our case, can present different sustainability characteristics depending on the production model and local conditions. By production model we mean the feedstock agricultural production system, the processing path and the socio-economic interfaces between ethanol producing enterprise and the local community.

To bring the ethanol sustainability discussions to a more scientific and objective level it is interesting to present the alternatives of production models in an organized way and to have sustainability indicators from the three dimensions (economic, social and environmental) to evaluate objectively each one. We propose basically three models: High Technology Model (large scale, state of the art technology, verticalized production and processing, maximum efficiency and lowest cost), Medium Technology Model (mixed sugarcane production – independent grower and mill production, scale compatible with agriculture production, balance between profits and social benefits), Social Model (small independent sugarcane producers and outgrowers, integration with food production and energy services for the local community, jobs); a fourth alternative, the Balanced Model, would be the one optimized as a function of the local conditions, driving forces, government policies, local culture and practices, land tenure profile and existing infrastructure, trying to take advantage of the best characteristics of the three basic models.

A preliminary approach to evaluate the alternatives of production models is suggested and illustrated considering conditions observed for ethanol production from sugarcane in Latin America and Sub Saharan Africa.

1. Introduction

Biofuels are not equal. They can be chemically similar, but depending on the production route, scale, production site, among other factors, biofuels present large differences spanning through aspects such as economic viability, land and water demand, greenhouse gas (GHG) emissions mitigation, jobs creation, technology level required in agriculture and processing; in other words, they differ in many of the aspects normally related to the sustainability. Of the many biofuels options in use today, bioethanol and biodiesel dominate clearly the alternatives for transport biofuels, and ethanol represents 80 % of total by volume (REN21, 2013). Although today most of the bioethanol is produced from corn (F.O. Licht, 2013), sugarcane shows a brighter future because it is already produced in more than a 100 countries (FAO, 2013). The regions with land available for agriculture expansion are located essentially in Latin America and Africa (Doornbosch and Steenblik, 2007) with land and climate adequate for sugarcane, and most of all, it is the biofuel feedstock with the best performance in terms of GHG emissions, land demand, fossil energy consumption and different forms of energy as co-products.

The recent fast expansion of biofuels production and use has brought to light several concerns about their sustainability, but the discussions have been, mostly, in generic terms with a strong bias toward the social issues – food security and land tenure – and with lack of science based data. In this aspect, the production model evaluation, as proposed in this paper, can help to provide a more sustainable alternative considering the local conditions, at a landscape level, and taking into account the important interfaces and interactions between the biofuel producing chain and the local community and environment. It is worth to note that the concept of ”production model” is more comprehensive than ”production system”. While the concept of production system is more focused on physical-economic issues, such as yields, input/output ratios and emissions, with a limited perspective of other aspects, as found in the general literature on bioenergy (FAO, 2008) and in specific studies, for instance evaluating biodiesel perspectives in South Africa (von Maltitz and Setzkorn, 2012), soybean bioenergy production system in India (Mandal et al., 2002) and different schemes for palm oil production for biodiesel (Wiecke et al., 2007), the production model concept goes beyond those usual technological aspects of the biofuel production and includes also the direct and indirect socio-economic implications (jobs creation, costs, revenues, etc.) and the institutional conditions, as schematized in Figure 1. Thus, the production model includes the production system.

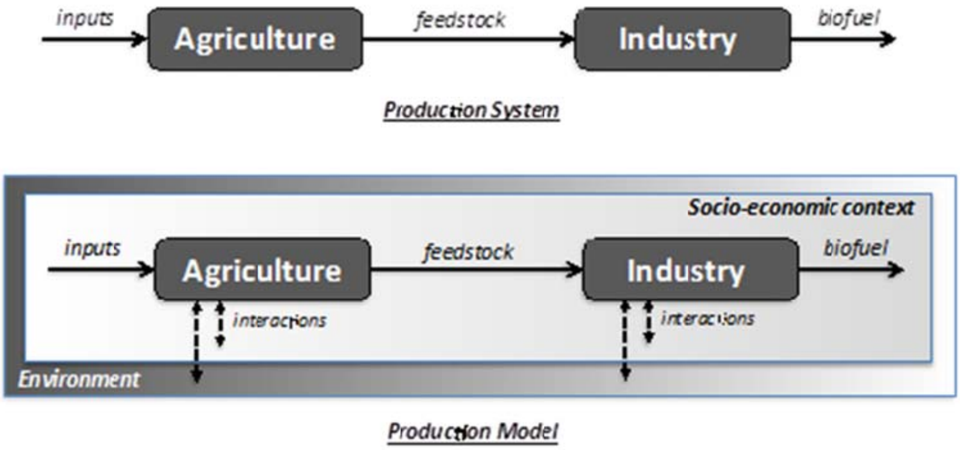

Figure 1. Production System and Production Model concepts

2. Production Model Alternatives

To bring the sugarcane ethanol sustainability discussions to a more scientific and objective level, it is interesting to present and analyze alternatives of production models in an organized way and to have sustainability indicators of the three dimensions (economic, social and environmental) to evaluate objectively each one. There are several basic aspects that will have different impacts in the three dimensions:

2.1 Scale of production

The size of the processing plant will play an important role on the economics of the project since there is a strong economies of scale in the ethanol distilleries in terms of investment costs, technology level used (boilers steam pressure/temperature, automation, process and energy efficiency), operating costs and yields. As shown in Table 1, increasing the daily capacity of distilleries from 120,000 L to 1,000 m^3, it is observed a 72 % reduction in the specific capital cost. Due to more efficient process, mainly in the juice extraction and fermentation sectors, feasible in high capacity mills, the typical ethanol yield of large distilleries exceeds 85 L/t sugarcane, while in small units (up to 5,000 L/d) this yield is in the range of 45 to 60 L/t. For a 28,000 L/d distillery operating in the South of Brazil it is reported a 10 years average yield of 62 L/t of sugarcane (Fleck et al., 2011). Depending on the destination of the ethanol produced, this yield affects directly the economic feasibility of the distillery.

The feedstock supply model is also directly affected by the scale as technology and mechanization, supply risk and logistics will depend on the area cultivated with cane and the cane transport distances. The increase of average feedstock transport distance associated to the increase of mill capacity can be, under *proper conditions, compensated by the densification of sugarcane fields near the mill. For instance, the values of this average distance observed in the 2008/2009 harvest season in the Brazilian states of São Paulo, Goiás and Mato Grosso were respectively 25.1 km, 22.8 km and 22.7 km, indicating that the new and relatively larger mills, located in the last two states, are planting sugarcane closer to the mill (MAPA, 2010).*

Table 1: Impacts of Distillery Size on the Investment Costs

Distillery ethanol capacity (L/d)	Daily milling (tc/day)[a]	Annual milling (tc/y)[b]	Cost (Million USD_{2007})[c]	Specific cost (USD/tc/y)
120,000	1,500	270,000	51	187
180,000	2,250	405,000	56	139
240,000	3,000	540,000	62	114
360,000	4,500	810,000	73	90
500,000	6,250	1,125,000	84	75
1,000,000	12,500	2,250,000	118	52

Notes: [a]tc=tonnes of cane; [b]180 days of effective milling; [c]converted from BRL by the authors
Source: Olivério, 2007

2.2 Feedstock production scheme

Verticalized production (the plant owner will produce and harvest the cane), outgrower (medium size independent producer) or small grower (family producer) are the basic options that may dictate the agricultural technology level used (cane varieties, agricultural management, mechanization level, cane payment system, yields), the production cost and reliability of supply.

As sugarcane shows a relatively short optimal harvesting period (few weeks), when the sucrose content (POL) is maximum in the cane stems, and considering that early and late ripening varieties are available, it is always relevant to coordinate and manage properly the planting (1 to 3 months) and harvesting (4 to 7 months) operations.

2.3 Socio-economic interfaces

The enterprise and the local community will have many interfaces and they must be well defined to accrue the highest benefits for both sides; this will probably be the most sensitive area with an enormous importance in the final outcome of the business, especially public acceptance. The distillery will provide jobs, agriculture extension and other capacity building, infrastructure (roads, storage facilities, transport, schools, health care), water for agriculture and population, energy services (electricity, cooking fuels) and food supply; the community will contribute with labor, land lease and/or cane supply.

With this in mind, we can suggest three basic production model alternatives and a fourth optimized alternative, the Balanced Model:

- High technology model: largest scale possible, vertical production and processing of sugarcane, maximum efficiency in products and energy conversion; it is focused on profit maximization with the lowest risk and full control the feedstock production, but tend to neglect some important social aspects.
- Medium technology model: mixed sugarcane production (independent growers and mill cane production) and scale compatible with the adequate cane production; some economic gains are sacrificed to get better social impacts (jobs, land tenure, public acceptance).
- Social model: small independent sugarcane producers (in cooperatives or not) and outgrowers with good integration with food production, energy supply and maximized job creation (with some sacrifice of the quality of the jobs); it must be very well defined and structured to be economically viable.
- Balanced model: it will depend strongly on the driving forces that motivated the enterprise, the local conditions and existing public policies and government priorities; it requires a maximum integration of the stakeholders' priorities and desires, but must be economically viable in the medium term without subsidies. This would be the model optimized for the local conditions and priorities and may have economic penalties when compared with the high technology model.

3. Production Model Selection Criteria

The make an organized choice of the best production model for the specific conditions and context, criteria must be established to make the process objective and clear. Indicators must be selected to be able to compare, even if it is in a qualitative way, the different alternatives. The choice of these indicators need to take into consideration the local conditions, the driving forces to introduce biofuels, land availability, soil and water quality and others deemed important by the stakeholders. The several Sustainability Certification systems in use today, such as Roundtable of Sustainable Biomaterials (RSB, 2013), BONSUCRO (2013), Global Bioenergy Partnership (GBEP, 2011), can provide a long list of indicators to choose from, but, bearing in mind that this is not a biofuel certification process, the stakeholders could select in agreement the ones to be used and the degree of importance of each one in the prioritization process. To include all indicators in a system like GBEP that has a total of 24 indicators (eight for each sustainability pillar) would make the process complicated and confusing for those stakeholders not familiar with certification systems, but with a good notion about what is important for the country and the specific region. To exemplify a selection process based on qualitative evaluation of selected indicators we will use some of the GBEP indicators arbitrarily:

- *Environmental*: Lifecycle GHG emissions, water quality and land use (LU) and land use change (LUC) related to feedstock production;
- *Social*: Allocation and tenure of land for biofuel production, price and supply of a national food basket, jobs creation;
- *Economic*: Productivity, gross value added, infrastructure and logistic.

For each indicator we give a relative value in the form of: (+) better than average, (0) average and (-) worse than average, but for a more sophisticated process numerical values can be assigned to the indicators what would required a bigger effort from the evaluators. The key point is this process is the selection of the indicators to be evaluated which depends on the driving forces and the country and local conditions (capacity of investment, technology level, labour qualification, land tenure system, etc. An example is shown in Table 2, prepared assuming as reference the typical Latin American and Tropical Africa.

Table 2: Grading of indicators for the three suggested production models

Indicators	High Tech	Medium Tech	Social
Lifecycle GHG emissions	+	0	-
Water quality	+	0	-
LU and LUC related to feedstock	+	0	-
Allocation and land tenure for biofuel	-	0	+
Food price and availability	0	+	0
Jobs creation	-	0	+
Productivity	+	0	-
Gross value added	+	0	-
Logistic	+	0	-

High tech: large scale, high yields and processing efficiency, high mechanization level in agriculture and high automation in the distillery (less jobs, but higher quality), higher fossil energy use, lower production costs and financial risk.

Medium tech: average yields and processing efficiency, low mechanization and automation levels (more jobs, but lower quality), average fossil energy use, average productions costs.

Social: small scale, low yields due to lower technology levels (sugarcane varieties, lower fertilizers and herbicides use, minimum mechanization and automation), less useful co-products (electricity, solid fuels), lower impacts on existing land tenure and local staple food production, lower investment and high operating costs, higher financial risk.

Balanced: in this model there will be always optimized choices taking into consideration the local and national conditions and driving forces. In this case a compromise will be sought in terms of economic gains, social benefits and minimum impact on the environment. It is not shown in Table 2 because it is a combination of the other three alternatives, selecting the best characteristics of each one based on the priorities defined by the stakeholders for the specific case.

One critical issue is the mechanization of the agricultural operations since there are conflicting interests in jobs, energy efficiency and co-products, labour qualification and costs. Some other aspects such as infrastructure building for the local community the larger scale plants can do it more easily since it will represent a lower fraction of the total investment costs. The small scale plants will have difficulties to present high conversion efficiencies due to simpler systems as required by the economies of scale, especially in the juice extraction system and steam and power generation; the ultimate result will be a lower ethanol yield per tonne of cane processed that combined with an expected lower agricultural productivity (lack of access to the best sugarcane varieties, inadequate agricultural practices and lower use of inputs) will have a significant impact on the global ethanol yield per unit of cultivated area (litres of ethanol/hectare).

4. The Brazilian case

In Brazil, the sugarcane ethanol production model had an evolution highly driven by government policies and the necessity to become more competitive to face the fossil fuel prices and the sugar international market. Ethanol started to be produced in the dawn of the 20th century, driven by the necessity to create a new market for the sugarcane surplus caused by the low competitiveness of Brazilian sugar in the international market. The federal mandate to add 5 % ethanol in all imported gasoline in 1931 motivated the addition of annexed distilleries to most of the existing sugar mills (Walter et al., 2013); this process was accelerated in 1975 by the launching of the National Alcohol Program that targeted 20 % ethanol blend in the all gasoline consumed in the country in a tentative to reduce the oil imports that was causing a devastating impact on the country's balance of payment. The second oil shock in 1979 pushed the federal government to increase the ethanol use goals by the introduction of neat ethanol cars, to break the blend wall (not clearly seen yet in those days); this action caused the construction of autonomous ethanol distilleries, using cane juice only for ethanol production.
The investment in technology for the sugarcane and ethanol production reduced the costs of ethanol, alleviating the need for subsidies (Goldemberg, 2007). However, the abrupt drop in oil prices reduced the government interest in the Alcohol Program due to increased need for subsidies and lower demand for oil imports as a consequence of the growth in the national production. The hardships in the ethanol market that had to compete with low cost gasoline with diminishing subsidies brought the national ethanol production to a stagnation state in the mid 1980s that lasted until the beginning of the 21st century. In this period the autonomous distilleries were converted to sugar and ethanol mills to reduce the business risk by producing two products for different markets. Finally, the third product, surplus electricity, started to gain weight after the reform of the national electric power sector along the 1990s with an extensive privatization of an almost totally public sector; the creation of the Independent Power Producer and the liberalization of the transmission and distribution grids to transport power from the independent producers, paying tariffs controlled by the government (Leal and Macedo, 2004). The situation today is that the three production models coexist in the country (sugar only, sugar/ethanol and ethanol only), but more that 80 % of the ethanol and around 96 % of the sugar are produced in sugar mills with annexed distilleries; the sugar mill model that dominates the sugar from sugarcane production worldwide represents only 4 % of the processed cane (MAPA 2010). Along this process, the improvements in technology and gains in scale were driven by the need to reduce costs.
This short story was intended to show a real case where changes in the production models resulted from different driving forces motivated by energy security sometimes and market forces at other times. Public policies were fundamental to start and to manage these changes, although there were good and bad policies; market forces alone would have never caused all these modifications in a large, traditional and important sector.

5. Conclusions

As mentioned before, the sustainability of biofuels cannot be treated on a global scale, although there are better options than the others. It is fundamental in the process to define clearly what is meant by "better" because it certainly will depend on what we are trying to accomplish (driving forces): energy security, rural or country development, jobs, GHG mitigation or other. The differences in biofuels and feedstocks are important, but so are the local conditions and the production model that can be designed to optimize in a certain way the production of the chosen biofuel to maximize the benefits while minimizing the negative impacts on the environment and in the population, and be economically viable. There will always be conflicting demands among the three dimensions of sustainability. Taking the case of plant scale, a micro distillery and a large scale distillery with ethanol yields of 50 and 80 L per tonne of cane, respectively, considering the same sugarcane productivity and sugar content in cane, we can see that the micro distillery would require 60 % more land for sugarcane production, increasing the impacts of land use change, but reducing the impacts on land tenure and increasing the job creation.
The methodology presented here is very simple and not adequate to produce enough information for an important decision making process, but is the initial step in the development of a more sophisticated evaluation process of the alternatives possible to be implemented for the sugarcane ethanol production in several developing countries that have available agricultural land and could become important producers in the medium term. The advent of second generation technologies for biofuels will add a new dimension

to this methodology due to the need to recover the agricultural residues, what requires mechanical harvesting of sugarcane. We hope this is another small step in the direction of the integrated sustainability analysis of biofuels.

Acknowledgements

The authors are grateful to the São Paulo Research Foundation for the financial support to Project LACAf I (Process N^{o} 2012/00282-3) that made possible the development of the work covered partially in this article.

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