ELLA Policy Brief
ELLA Area: Environmental Management
ELLA Theme: Brazil's Ethanol Programme

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Evidence and lessons from Latin America

Mechanisation of sugarcane harvesting in Brazil has been shown to decrease environmental impacts and waste, while also increasing efficiency, energy cogeneration and thus sector profits and national energy security. Learning from Brazil's years of trial-and-error, other countries could build an ethanol production system with these benefits from the outset.

FROM MANUAL TO MECHANICAL HARVESTING: REDUCING ENVIRONMENTAL IMPACTS AND INCREASING COGENERATION POTENTIAL

SUMMARY

The pre-harvest burning of sugarcane leaves is a common practice that enables manual pickers to collect the crop quickly, suffering less personal injury. The burning process, however, has negative impacts on the environment, on human health and on the potential energy value of the plant. Mechanisation eliminates the need for burning, speeding up the collection process, eliminating harmful emissions from smoke, reducing crop wastage and thus increasing productivity in terms of energy generation. Electricity generated from sugarcane biomass can also be sold to the grid, increasing both producers' income and the national energy supply. This Brief uses the example of Brazil to illustrate the advantages and disadvantages of switching from manual to mechanised sugarcane harvesting, and shares Brazil's efforts to gradually phase-out manual harvesting and improve infrastructure to take advantage of cogeneration potential. The lessons learned might be useful for countries from other regions as they consider how to structure ethanol production from the onset in their own countries.

COMMON PROBLEM: DISINCENTIVES OF SWITCHING TO MECHANISATION

Developing countries tend to use manual harvesting when initiating ethanol production due to having a relatively cheap, abundant labour force. With manual harvesting comes the necessity to burn the awkward spiky leaves from the sugarcane crop, because these significantly slow workers down due to the physical harm that they can cause. In Brazil, as well as in other developing countries, although mechanisation is recognised as bringing significant productivity gains, the capital intensity of starting such a production system is a disincentive for start-up producers. Additionally, the co-benefits of generating energy from sugarcane biomass are often perceived to be outweighed by the large up-front costs of high pressure boilers and of connecting production facilities to the national grid.

KEY LESSONS LEARNED

Mechanisation of sugarcane harvesting can increase productivity and income generation

Eradicating pre-harvest burning can reduce environmental harm and increase energy cogeneration potential

The cogeneration of electricity from sugarcane biomass has been shown to be more efficient when using high pressure boilers

Brazil followed this least-capital-intensive path for the first decades of ethanol expansion, only later beginning to actively promote the switch to mechanisation. With the benefit of hindsight, other countries can see that the capital investment in harvesters and high pressure boilers reduces environmental impacts and increases income potential significantly.[1]

MANUAL VS. MECHANISED HARVESTING IN BRAZIL

This section provides an overview of manual and mechanised harvesting in Brazil, before turning to a discussion about the relative advantages and disadvantages of each practice. The following section then assesses Brazil's efforts to promote the switch to mechanised harvesting and to outfit their mills for cogeneration.

Background on Manual and Mechanised Harvesting

In Brazil, the sugarcane harvesting period varies according to precipitation patterns to ensure that cutting and transportation take place when the plant contains the highest accumulation of sugar. The traditional system of harvesting, still used in about 40% of planted areas, involves burning the tops and leaves of the sugarcane, called barbojo, to facilitate manual cutting. Manual harvesting can be carried out without necessarily pre-burning the crop, though doing so increases worker safety and productivity by quickly removing dry leaves and potentially harmful pests from plantations.

Figure 1: Harvester Collecting Sugarcane and Filling the Tractor Trailer
Source: Pedro Ninô de Carvalho

Mechanised harvesting refers to using mechanical harvesters to crop sugarcane plantations. The harvester works 24 hours per day during the harvesting season, cutting the cane and throwing it into the tractor trailer before taking it to the mill where the cane is processed. Due to the fact that the harvester works round-the-clock and is able to collect 20 tonnes of

Table 1: Manual and Mechanised Sugarcane Harvesting in Brazil, 2008/2009

State/Region	Mechanical Harvesting	Manual Harvesting	Sugarcane Production in 2008/2009 (tonne)	Production as a Percentage of Total Brazilian Production
São Paulo	52.4%	47.6%	352,277,735	61.5%
Paraná	81.6%	18.4%	44,497,582	7.8%
Minas Gerais	62.5%	37.5%	41,818,865	7.3%
Goiás	51.2%	48.8%	29,806,046	5.2%
Total Centre-South Region	**57.2%**	**42.8%**	**508,531,567**	**88.8%**
Alagoas	91.8%	8.2%	27,309,285	4.8%
Pernambuco	99.8%	0.2%	18,949,518	3.3%
Total North-Northeast Region	**94.7%**	**5.3%**	**64,231,460**	**11.2%**
Total Brazil	**62.9%**	**37.1%**	**572,763,027**	**100.0%**

Source: National Supply Company (*Companhia Nacional de Abastecimento* - CONAB). 2010. *Perfil do Setor do Açúcar e do Álcool no Brasil* (*Profile of the Sugar and Alcohol Sector in Brazil*). CONAB, Brasília.

sugarcane per hour, harvesting time is cut considerably. Mechanised harvesting requires specific conditions that entail planning during the planting of the crop. The seeds must be planted on flat ground, with a specific distance between the rows, closer to the surface than for manual harvesting. Also, the plant must grow straight upright, with no bends. In terms of harvesting and post-harvesting, producers perceive some key disadvantages, such as that the harvester cannot cut as close to the ground as a manual harvester, which reduces the average length of sugarcane collected. Other disadvantages from the producer perspective are that re-growth of the stumps is less uniform, making subsequent harvests less effective, and compaction under the weight of the tractor negatively affects the quality of the soil.

Manual and Mechanised Harvesting: Advantages and Disadvantages

In the case of manual harvesting, the burning of barbojo has shown to increase productivity two-fold; on average, workers

[1] For more information, see: Bajay, V. 2011. Food, Fuels, Electricity and Materials from Sugarcane in Brazil: Costs, Benefits and Challenges. *International Journal of Environmental Studies* 68 (2) 145-159.; Johnson, F., Seebaluck, V. (eds). 2012. *Bioenergy for Sustainable Development and International Competitiveness: The Role of Sugar Cane in Africa*. Routledge, Oxford.; Martinelli, L., Filoso, S. 2008. Expansion of Sugarcane Ethanol Production in Brazil: Environmental and Social Challenges. *Ecological Applications* 18(4) 885 – 898.; Smeets, E. et al. 2008. The Sustainability of Brazilian Ethanol - An Assessment of the Possibilities of Certified Production. *Biomass and Bioenergy* 32 (8) 781-813.; Goldemer, J., Coelho, S., Guardabassi, P. 2008. *The Sustainability of Ethanol Production From Sugarcane*. *Energy Policy* 36 (2008) 2086– 2097.

cut twelve tonnes when the barbojo has been burned away before harvesting, against six tonnes of green-cane with the barbojo intact in the same amount of time. Burning also reduces the cost of transportation, as the heavy and bulky leaves are burned and do not need to be carried to the mills.[2]

Even though the burning is 'controlled' in a delimitated area for a maximum duration of ten minutes, it still represents a risk to grid cables, roads, workers, inhabitants of producing cities and biodiversity. There are some other clear environmental risks as well, such as the death of a large number of animal species because of the burning temperature, which may reach 800°C.[3]

Moreover, the heat from burning reduces the amount of water in the soil and changes the structural characteristics of the ground. It thereby triggers erosive effects, and causes the occurrence of runoff, with resulting loss of soil nutrients and water, due to reduced vegetation cover. Additionally, it may compromise or destroy water sources due to erosion and siltation when riparian forests are destroyed by the fire.

Sugarcane burning also emits high levels of particulate matter, carbon monoxide, nitrogen oxides, sulphur oxides and methane. It causes serious health problems for workers, who breathe in the soot while working, as well as those who live in ethanol producing regions. Urban pollution gets even worse during the winter, the peak of harvesting season, when thermal inversions occur frequently.[4]

Table 2, below, highlights some of the key economic disadvantages and environmental impacts of burning. It also illustrates the advantages perceived by ethanol producers.

One of the key drawbacks of switching to mechanised harvesting is job losses. In recent years, thousands of unskilled workers have lost their jobs, since one harvester replaces up to 100 workers. Table 3, below, compares sugarcane employment in 1997, before mechanisation, then again after the introduction of fully mechanised harvesting.

On the other hand, the use of water provides a good example of the economic co-benefits of environmental restrictions on the practice of burning. If harvesting is manual and barbojo is burned, the sugarcane needs to be washed with a large amount of water, approximately 2.2 m^3 for every tonne of sugarcane, according to the Manual of Water Use and Conservation in the Sugarcane Agro-industry by the Brazilian National Water Agency. When harvesting is mechanised, there is no soot on the cane so it does not need to be washed. There are procedures to clean the biomass which do not involve water, meaning mechanisation significantly reduces the water intensity of ethanol production.

Table 2: Advantages and Disadvantages of Pre-harvest Sugarcane Burning

Disadvantages		Advantages
Economic Drawbacks	**Environmental Impacts**	**Positive Aspects**
Damage to the sugarcane tissue, reducing yields	Soil degradation and erosion	Worker safety
Reduction in soil fertility	Emissions of PM, CO CH_4, CO_2, SOx, NOx	Increased productivity of manual workers
Purification difficulties make production costly	Biodiversity loss	Job creation
When burned, sugarcane rots more quickly, so it must be used faster	Health problems, especially in the respiratory system	Inexpensive
Necessity of using large amounts of water	Degradation of riparian forests	Reduction of transportation cost

Own elaboration.

Table 3: Impact of Mechanisation on Employment

Region	Number of employed workers pre-mechanisation, 1997	Number of employed workers after mechanisation	Employment reduction, as % of 1997 employment
North	2,043	198	90%
North-east	225,911	119,334	47%
Mid-west	35,746	11,036	69%
South-east	194,669	95,320	51%
South	52,282	11,487	78%
Total Brazil	510,651	237,375	54%

Source: Guilhoto et al. 2001. *Emprego e Mecanização na Colheita da Cana de Açúcar: Diferenças Regionais* (*Employment and Mechanization in the Sugarcane Harvest: Regional Differences*). Unpublished manuscript.

[2] Ripoli, T.C.C., Molina. W.F., Ripoli, M.L.C. 2005. *Manual Prático do Agricultor – Máquinas Agrícolas (Practical Agriculture Manual – Agricultural Machines).* Edição dos autores v.1. Piracicaba, SP.; For more information about sugarcane harvesting, see: Braunbecka, O. et al. 1999. Prospects for Green Cane Harvesting and Cane Residue Use in Brazil. *Biomass and Bioenergy* 17 (6) 495 – 506.
[3] Ferraz, G. 2007. *Projeto Programa de Pesquisa em Políticas Públicas: IX Workshop de Pesquisa sobre Sustentabilidade do Etanol (Research Programme on Public Policies: IX Research Workshop on Sustainability of Ethanol)*. São Paulo, SP.
[4] For more information about environmental impacts from burning, see: Arbex, M. 2007. Air Pollution From Biomass Burning and Asthma Hospital Admissions in a Sugar Cane Plantation Area in Brazil. *Journal of Epidemiol Community Health* 61 395-400.; Pozza, S. et al. 2009. Sources of Particulate Matter: Emission Profile of Biomass Burning. *International Journal of Environment and Pollution* 36 (1) 276-286.

PROMOTING MECHANISATION AND IMPROVING COGENERATION POTENTIAL

As demonstrated above, both manual and mechanised harvesting have their advantages and disadvantages. In particular, there are some key disincentives that make it less likely producers will want to make the switch to mechanised harvesting. Over time, Brazil's leaders concluded that the advantages outweigh the disadvantages, so the country has worked hard to progressively replace manual harvesting. Although burning continues to be a dominant practice, in Brazil it is gradually being replaced by mechanised harvesting of green-cane. The sections below describe some of Brazil's efforts to incentivise the switch to mechanised harvesting, as well as measures taken to enable producers to take advantage of one of the key benefits of such a switch: greater energy efficiency and cogeneration.

Supporting Legislation for Mechanised Harvesting: The Case of São Paulo State

São Paulo State is Brazil's primary ethanol producing area, accounting for 61.5% of the country's total production. São Paulo also offers an excellent case study in using legislation to gradually enforce a switch from manual to mechanised harvesting. Because of the many negative effects of burning, environmental legislation establishing the phase-out of barbojo burning in the State of São Paulo was introduced in 2002 (State Law 11.241, 19 September, 2002).

The following table shows the schedule to phase-out burning according to state law. The law took into account the fact that mechanisation is only possible in approximately 50% of the North-eastern areas and 80% of the rest of the country, because the existing technology for mechanised tractors does not allow for harvesting on slopes with a gradient of more than 12°.

The state law was followed by the Green Protocol, a document that was voluntarily signed in 2007 by the Government of São Paulo State and the Sugarcane Agro-industrial Sector of São Paulo State. The agreement brought forward the phase-out date of pre-harvest burning. The elimination of barbojo burning in the State was brought forward from 2021 to 2014, and the percentage of green-cane harvesting was increased from 50% to 70% by 2010. For plantations where the land is at an incline of greater than 12°, the Protocol brought forward the elimination of burning from 2031 to 2017 and increased the harvesting of green-cane from 10% to 30% by 2010.

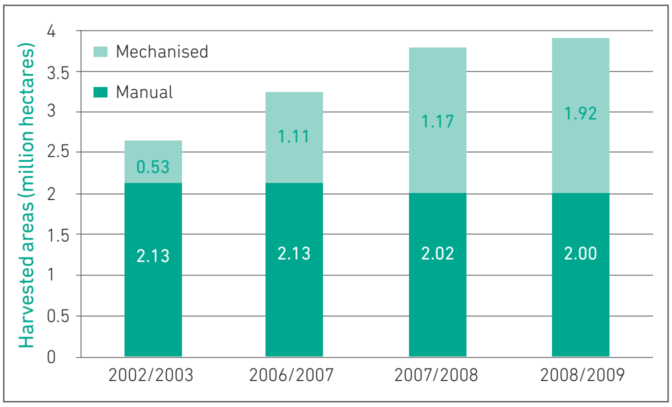
Table 4: Schedule for Eliminating Burning in São Paulo State, 2002 State Law

Year	Burning prohibited in areas that can be mechanised	Burning prohibited in areas where mechanisation is not currently possible
1st year (2002)	20% of harvested area	-
5th year(2006)	30% of harvested area	-
10th year (2011)	50% of harvested area	10% of harvested area
15th year (2016)	80% of harvested area	20% of harvested area
20th year (2021)	100% of harvested area	30% of harvested area
25th year (2026)		50% of harvested area
30th year (2031)		100% of harvested area

Source: Legislative Assembly of Sao Paulo State.

São Paulo has seen a substantial increase in mechanical harvesting as a result of both the 2002 State Law and the Green Protocol. As seen in Figure 2, from 2002 to 2006 mechanised harvesting increased 100%, and from 2006 to 2008 it further increased more than 70%. In addition, State and local governments are developing and implementing mechanisms to encourage producers to respect the law. Producers that do not comply and continue to burn barbojo before manual harvesting will be penalised and charged a fine. This will mean that the environmental cost of burning will be ultimately paid for by producers, making ethanol more expensive and less competitive. It is hoped that this legislation will give producers an economic incentive to adopt more efficient and environmentally-friendly practices.

Figure 2: Evolution of Mechanical Harvesting in São Paulo State Since the Introduction of Law 11.241/2002



Source: São Paulo Secretary of Environment, 2010 (*Secretaria de Meio Ambiente* - SMA).

Putting Biomass to Productive Use: Cogeneration

One of the key benefits of switching to mechanisation is the higher volume of biomass made available for productive use. This additional biomass, in the form of barbojo, need not be wasted through burning or disposal. Instead, sugarcane biomass can be converted into electricity, through the process of cogeneration.

Thermal conversion of non-fermentable biomass to steam, and thus electricity, is achieved by employing biomass-fired boilers with steam turbine systems. Using high-pressure boilers reduces energy waste and increases efficiency, allowing mills to generate much more energy per unit of biomass. The higher the pressure, the greater the energy efficiency gain. The additional biomass collected by eradicating pre-harvest burning could be processed along with the bagasse in the boilers to produce energy that can be exported to the National Interconnected System. Indeed, the barbojo corresponds to approximately 33% of the energy potential of sugarcane.[5] Thus the switch from manual to mechanised harvesting, when coupled with the switch to high pressure boilers, enables producers to increase income by exporting energy to the grid.

> **Cogeneration**
>
> Cogeneration is the sequential generation of two forms of useful energy from a single primary energy source. Typically, the two forms of energy are mechanical energy and thermal energy. In the sugarcane sector, electricity and thermal energy are produced through the use of biomass.

Despite the economic and environmental advantages, the potential for biomass utilisation is still largely untapped. Some reasons include the difficulty in connecting thermal power to the grid, economic and financial fragility, as well as lack of experience in operating this electricity-generating part of the mill.

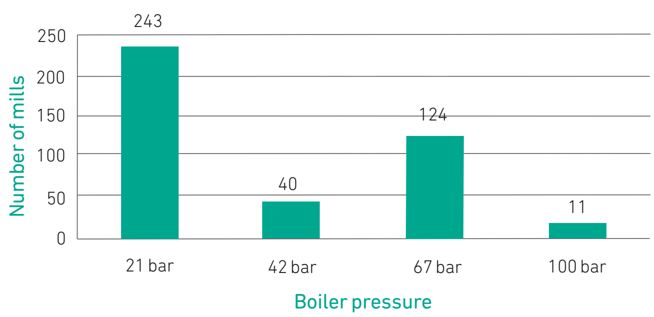
Today in Brazil there are approximately 418 mills nationwide. Although many are connected to the national grid, the majority are net energy importers. Many plants have long employed cogeneration technologies for on-site consumption which does not require high pressure boilers, though have not yet considered expanding cogeneration potential for export. It is much more expensive to adapt an inefficient plant and connect it to the grid than to build an efficient plant from the outset. In addition to cogeneration upgrades, many retrofit projects also require optimisation of the production process in order to create enough electricity to export.[6]

Only about 25% of Brazil's mills export electric energy to the grid.[7] As Figure 3 shows, the majority of mills work with low pressure boilers (21 to 42 bar). Only 135 mills have the potential to export energy, thanks to their high pressure boilers (67 or 100 bar).[8] In fact, in the last five years, only 83 mills actually exported electricity to the grid.

Since 2004, with the restructuring of the Brazilian electricity sector, cogeneration has increased its share of the energy market. National policies like special loans from the Brazilian Development Bank (*Banco Nacional de Desenvolvimento Econômico e Social* - BNDES) to replace low pressure boilers with high pressure ones, have encouraged the adoption of practices that mitigate environmental impacts either directly or indirectly.

Cogeneration is contributing to national energy security and diversification of the Brazilian energy matrix. An additional advantage is that electricity generated has been able to complement hydroelectric generation, as harvesting takes place during the Centre-South Region's dry season.[9]

Figure 3: Mill Distribution According to Boiler Pressure



Source: Nascimento, D. 2012. Projetos de Alta Pressão (High Pressure Projects). *Idea News Magazine* 11 (140) 34-43.

[5] Industry Association for Energy Cogeneration (Associação da Indústria de Cogeração de Energia – COGEN). 2009. *Bioelectricidad: Reduzindo Emissoes e Agregando Valor ao Sistema Eléctrico Nacional (Reducing Emissions and Adding Value to the National Electric System)*. Presentation at Ethanol Summit, São Paulo, 2009.
[6] Nyko, D. et al. 2011. *Determinants of Low Utilisation of Electrical Potential from Sugarcane Industry*. BNDES Setorial 33. Rio de Janeiro.
[7] Lima, W. 2012. Most of the Energy Will Come From Cogeneration by 2020. *Jornal da Cana* 2(222) 40.
[8] Nascimento, D. 2012. Projetos de Alta Pressão (High Pressure Projects). *Idea News Magazine*, 11(140) 34-43.
[9] For more information about cogeneration in Brazil, see Granville. S. et al. 2007. *Sweet Dreams are Made of This: Bioelectricity in Brazil*. Power Engineering Society General Meeting, Tampa, FL, USA.; Braunbecka, O. et al. 1999. Prospects for Green Cane Harvesting and Cane Residue Use in Brazil. *Biomass and Bioenergy* 17 (6) 495-506.

CONTEXTUAL FACTORS

ENABLING BRAZIL'S POLICY RESPONSE

Environmental public policies played a role in forcing ethanol producers to change old practices, notably those that established a phase-out for sugarcane burning. In addition, special loans provided by the Brazilian Development Bank (*Banco Nacional de Desenvolvimento Econômico e Social* – BNDES) for the acquisition of mechanical harvesters were also important in complementing the phase-out policy.

In terms of increasing efficiency and national energy security, the government, again through BNDES, created special financing lines to aid the replacement of low pressure boilers with high-pressure ones. Low interest, long-term loans to finance purchases of new technology were strategic and fundamental in encouraging the uptake of efficient machinery, and thus cogeneration capacity.

These policies were enabled by two main factors: public pressure and the strengthening of public environmental management, both of which were spurred by international trends. Public pressure increased as a result of improved environmental awareness, and public environmental management has been increasing in strength since the 1970s. State capacity increased in terms of environmental control, supervision and scientific research in the same period that the government began to incentivise ethanol production. As a result, the central administration and regional governments were able to develop and enforce policies related to the ethanol sector.

LESSONS LEARNED

1. Eradicating the practice of pre-harvest burning increases production efficiency, and the Brazilian case has shown how to make this possible. In addition to causing various negative environmental impacts and affecting human health, burning also effectively wastes one-third of the crop's available energy.

2. In Brazil's sugar and ethanol industries, adopting mechanical harvesting was a key factor in increasing the eco-efficiency of production. Adopting mechanisation raised the energy balance, enlarged production income and reduced environmental impacts.

3. The shift to mechanisation has proved to be negative for job creation, but on the other hand, for producers the benefits in terms of increased efficiency and reduced environmental impacts still can make mechanisation an attractive option.

4. If barbojo is burned in boilers along with the bagasse, steam and electricity can be generated to supply power for the operation of ethanol plants. Surplus electricity can be sold to third parties, adding value to production. This increase in energy generation can complement other energy sources and help increase energy security.

5. The amount of electricity generated from sugarcane waste can be further enhanced by adopting the use of more efficient generators. Increasing boiler pressure has proven to be the primary method for increasing efficiency.

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