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Sustainability assessment of sugarcane-ethanol production in Brazil: A case study of a sugarcane mill in São Paulo state

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ABSTRACT

To improve decision-making, sustainability-based approaches to impact assessment demand that we move beyond narrowly defined considerations to address the full suite of requirements for sustainability, as well as the interconnections, feedbacks and uncertainties that typify complex socio-ecological systems at all scales. This paper applies a sustainability assessment framework to assess a sugarcane-ethanol mill in São Paulo state, Brazil, seeking to identify opportunities for improvements towards sustainability. The analysis highlights the importance of broader strategic planning for providing an appropriate context for more sustainable sugarcane-ethanol production at the watershed, municipal, and mill level. Five particularly important multi-scalar issues that were identified are (1) the maintenance of long-term water availability and quality; (2) the enhancement of biodiversity and reversal of ecological fragmentation; (3) the planned elimination of sugarcane straw burning and subsequence increase in mechanized harvesting; (4) the impacts of indirect and direct land-use change; and (5) the quality, availability and durability of livelihood opportunities. To address these issues requires long term integrated planning and monitoring, better understanding of cumulative impacts and thresholds, recognition of important tradeoffs, and a credible and collaborative decision-making process that involves and empowers stakeholders to set the agendas and seek common goals.

1. Introduction

In order for humanity to address the interrelated challenges facing us we must improve our decision-making processes such that they move beyond narrowly defined considerations to address as much as possible the full suite of requirements for sustainability, as well as the interconnections, feedbacks and uncertainties that typify complex socio-ecological systems at multiple scales (Gibson et al., 2005). One potential tool for such decision-making is "Sustainability Assessment", a framework for integrated assessment that attempts to identify, predict and evaluate the potential impacts of undertakings and their best alternatives for progress towards sustainability. These undertakings can be at both project and strategic (programme, plan, and policy) levels, and for proposals as well as on-going initiatives (Gibson et al., 2005; Devuyst, 1999; Pope et al., 2004).

This article describes an application of Gibson's sustainability assessment framework to assess a sugarcane ethanol production mill in São Paulo, Brazil, seeking to identify opportunities for improvements towards sustainability (Gibson, 2006a). Gibson provides eight generic requirements for progress towards sustainability that must be specified for the particular context to supply a comprehensive set of evaluation and decision criteria (Gibson et al., 2005; Gibson, 2006a) and the framework has been applied for energy systems both at the strategic level, assessing the proposed Ontario Electrical Systems Plan (Winfield et al., 2010), as well at the on-going project level, assessing a small-scale biodiesel operation (Gaudreau and Gibson, 2010).

The assessment highlights the importance of both strategic and project level implications that must be understood within the local context of the mill and its watershed, and this research provides a unique attempt to integrate important findings across these scales, from the local to the international and vice versa. The analysis provides key recommendations for decision-making that should help ensure the expected growth in Brazilian sugarcane ethanol production is undertaken in a

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manner that improves the long-term welfare of Brazil and São Paulo.

2. Rationale – the broader context of Brazilian sugarcane ethanol

Brazil is currently the world's largest producer and exporter of sugar, the largest exporter of ethanol, and second largest producer of ethanol (MDIC, 2010), and growth is expected to continue in coming years due to rising domestic and international demand. While sugarcane ethanol promises advantages in the form of fuel substitution, climate change mitigation, employment opportunities and economic growth (Martinelli et al., 2011), the sector is facing criticism on many fronts. Sugarcane production is associated with various adverse environmental and health impacts including land degradation and deforestation in the Savannah (Schlesinger et al., 2008; Sparovek et al., 2009); direct and indirect land-use change (Gallardo and Bond, 2011; Lapola et al., 2010); soil and water pollution (Smeets et al., 2008); loss of biodiversity due to monocultures and straw burning (Schlesinger et al., 2008); and carcinogenic air emissions from sugarcane straw burning (Avolio, 2002; Ometto et al., 2009; Schaffel and La Rovere, 2010). Furthermore, the expansion of sugarcane crops has worsened inequality in the countryside and promoted poor working conditions through overworking, low wages, the use of temporary and seasonal labour, and even child and slave labour (Schlesinger et al., 2008; Repórter Brasil, 2010; Nuffield, 2011).

In order to mitigate the adverse impacts of sugarcane ethanol, the federal and state governments have developed regulatory and voluntary measures that include new zoning laws, environmental regulations (e.g. to eliminate sugarcane waste burning by 2014 São Paulo state), and workers rights commitments (e.g. the voluntary National Commitment for the Improvement of Labour Conditions in Sugarcane Production) (Martinelli et al., 2011; SGPR, 2009; SMA, 2008). Such efforts are a notable first step to improve decision-making, regulation and practice at all scales (local, state and federal), but more is needed to ensure sufficient attention to, and integration of, sustainability concerns at higher levels of decision-making. For example, Brazilian Environmental Impact Assessments examine the biophysical and social aspects of particular projects, but many important concerns and opportunities lie at the regional level (Gallardo and Bond, 2011), and Brazil still lacks a legislated strategic environmental assessment protocol (de Oliveira et al., 2009). This research provides a unique attempt to bridge the project-strategic level divide to help ensure that the manner in which sugarcane-ethanol unfolds in Brazil provides the best opportunity to obtain mutually reinforcing positive gains and avoid worsening the environmental and social challenges facing the industry.

2.1. The case specific context

This section provides a brief introduction to the case context, while further elaboration is provided in Sections 5 (initial observations) and 6 (discussion of important findings). The sugarcane ethanol mill under investigation is located in the central region of São Paulo state, and harvests approximately 21,000 ha of sugarcane crops from seven municipalities in three different watersheds. The mill produces hydrated ethanol for domestic markets, and sugar for domestic and international markets. The most important watershed where the mill is located is the Tietê-Jacaré Watershed, an important producer of sugar and ethanol; its twenty-two mills account for thirteen percent of production in São Paulo state, and eleven percent of national production (CBH-TJ, 2010; CPLA/SMA, 2011). In the municipality where the industrial plant of the mill is located, land under sugarcane cultivation increased by ninety percent between 2003 and 2010 (INPE, 2011), and sugarcane now covers one quarter of the total area (approximately 300,000 ha) and supplies several mills. The mill under investigation has plans for additional increases in land under cultivation in the following years.

The 2008 GDP per capita of the Tietê-Jacaré Watershed was US$9840,[2] which is slightly higher than the national average (US$9310), but trails the average of São Paulo state (US$11,950) (CBH-TJ, 2010). The economy of the Tietê-Jacaré Watershed is dominated by ethanol and sugar both from sugarcane, as well as the production and processing of citrus, primarily oranges. While still primarily agricultural, the regions of the watershed are diversifying into pulp and paper, beverages, footwear, metalworking, mining, leather tanning and ecotourism (CBH-TJ, 2010).

The Tietê-Jacaré Watershed is already experiencing environmental constraints. In 2008, the watershed was in a state of alert over water because 48.5 percent of supply had already been appropriated for human uses (up from 32 percent in 2007), and this is close to the 50 percent ratio that is considered a critical threshold (CBH-TJ, 2010; CPLA/SMA, 2011). The sub-basin of the industrial plant is polluted due to improper sewage treatment (from lack of urban water treatment capacity), and non-point source pollution from agricultural and urban areas. Likewise agriculture, cattle raising and improper tourist practices are worsening soil erosion and causing gully formation. Several municipalities in the basin are approaching ozone (a precursor to smog) saturation, which may limit further expansion of electricity production from bagasse.[3]

Regarding land use, the watershed lost 20,000 ha of natural vegetation between 2005 and 2009; currently 91,400 ha remain (CPLA/SMA, 2011). The vegetation index of the watershed was eight percent in 2009, less than half of the twenty percent index of vegetation cover São Paulo state has targeted by 2020 (CPLA/SMA, 2011). The remaining natural vegetation is highly fragmented; more than 95 percent of vegetation fragments are smaller than 100 ha, thereby increasing isolation of populations of plants and animals and threatening genetic diversity (von Glehn, 2008).

Future development in Tietê-Jacaré Watershed, whether for agricultural, industrial, commercial or residential purposes, will be increasingly subject to biophysical constraints, notably for land, water, air quality, and biodiversity. These concerns have social and cultural implications as well, including livelihood opportunities, the maintenance of natural capital, and quality of life. The sugarcane ethanol industry must become far more proactive in the face of rising sustainability concerns, as even maintaining the economy in its current state may not be possible.

3. Methodology

This section provides a general description of Gibson's framework for sustainability assessment; more in-depth descriptions are treated elsewhere (Gibson et al., 2005; Gibson, 2006b). It is noted that Gibson's framework for sustainability assessment is complementary to other strategic level frameworks (Partidário et al., 2009; Teigão dos Santos and Partidário, 2011; Svarstad et al., 2008). The basic approach centres on combining established sets of generic sustainability and resilience criteria in the specification of an evaluation framework for the particular case and context. Gibson proposes a basic set of categories and criteria that are applicable to a wide range of evaluations. This set is shown in Table 1 (Gibson, 2006b).

[2] US$1.00 = R$ 1.635 (September 2,16h59, 2011).

[3] Bagasse is "the dry pulpy residue left after the extraction of juice from sugarcane, used as fuel for electricity generators, etc." (Oxford English Dictionary).

Table 1
Gibson's sustainability assessment decision criteria (Gibson, 2006b).

Socio-ecological system integrity Build human-ecological relations to establish and maintain the long-term integrity of socio-biophysical systems and protect the irreplaceable life support functions upon which human as well as ecological wellbeing depends.
Livelihood sufficiency and opportunity Ensure that everyone and every community has enough for a decent life and that everyone has opportunities to seek improvements in ways that do not compromise future generations' possibilities for sufficiency and opportunity.
Intragenerational equity Ensure that sufficiency and effective choices for all are pursued in ways that reduce dangerous gaps in sufficiency and opportunity (and health, security, social recognition, political influence, etc.) between the rich and the poor.
Intergenerational equity Favour present options and actions that are most likely to preserve or enhance the opportunities and capabilities of future generations to live sustainably.
Resource maintenance and efficiency Provide a larger base for ensuring sustainable livelihoods for all while reducing threats to the long term integrity of socio-ecological systems by reducing extractive damage, avoiding waste and cutting overall material and energy use per unit of benefit.
Socio-ecological civility and democratic governance Build the capacity, motivation and habitual inclination of individuals, communities and other collective decision-making bodies to apply sustainability requirements through more open and better informed deliberations, greater attention to fostering reciprocal awareness and collective responsibility, and more integrated use of administrative, market, customary and personal decision making practices.
Precaution and adaptation Respect uncertainty, avoid even poorly understood risks of serious or irreversible damage to the foundations for sustainability, plan to learn, design for surprise, and manage for adaptation.
Immediate and long term integration Apply all principles of sustainability at once, seeking mutually supportive benefits and multiple gains.

3.1. Data collection

The research adopted a case study approach to data collection (Yin, 2009). A variety of methods were applied, including key stakeholder interviews, document analysis, and direct observation. By using multiple methods it is possible to obtain triangulation of results and improve construct validity (Yin, 2009).

In total, fourteen stakeholders were interviewed. They represented a broad set of backgrounds, expertise and experience, including the municipal level secretary of the environment, two technical analysts from the Municipal Department of the Environment, two technical analysts from the State Department of the Environment, two members of the regional tourism association, the environmental manager of the mill, the assistant for training and corporate responsibility of the mill, the work safety manager of the mill, three local residents, and a former sugarcane cutter. Due to the broad and comprehensive nature of the analysis, the interviews were open-ended, but still guided by the full suite of requirements for progress towards sustainability. The interviews were analysed for relevant themes – both general and specific – relating to sugarcane and sugarcane-ethanol production. The interviews were not audio recorded.

Beyond the formal interviews, members of the research team attended five multi-party meetings that included stakeholders from environmental and civil society non-governmental organizations, government representatives from agriculture and planning, and environmental enforcement. All attempts were made to cover all relevant perspectives, and ensure that all stakeholders were provided a positive environment for contributing insights.

To supplement the interviews, the research team also drew from a wide variety of documents relating to sugarcane and sugarcane-ethanol production in Brazil, São Paulo state, and the watershed. The documents were identified through various means, including the city hall website, the watershed committee, as well as from the interviewees. The documents were also supplemented by the broader academic literature relating to sugarcane-ethanol production in Brazil.

The final approach to data collection was direct observation, including multiple site visits to the sugarcane fields and the ethanol process plant. The direct observations helped situate the broader concerns and insights into the more immediate context of the mill under assessment, and allowed the research team to develop a richer understanding of the realities behind the standard accounts and common assumptions.

4. Sustainability assessment criteria

Over the course of one year of data collection and analysis, the research team developed a set of sustainability criteria relevant to the particular case and context. The sustainability criteria, presented in Table 2, were developed with guidance from the interviews, document analysis and site visits, and were approved by the various stakeholders, including representatives from the mill and the municipal government. The criteria were structured and organized within Gibson's sustainability assessment decision criteria presented in Table 1. The criteria were phrased as a series of questions that reflect important concerns of the case and context, as well as general (and often universal) requirements of progress towards sustainability. For practical application in policy and project deliberations in Brazil, the categories would need to be re-organized and expressed in terms that facilitate understanding and informed discussion among the relevant stakeholders (Gibson, 2006b), as long as the full suite of requirements for progress towards sustainability is respected.

The case specific sustainability criteria provided in Table 2 were initially addressed in a set of observations (i.e. qualitative and quantitative indicators) relating to the case and context presented in Table 3. The observations served to justify the proposed criteria set, as well as provide an initial analysis of the sugarcane-ethanol mill. While the observations are presented here after the sustainability criteria, in reality the criteria and the observations were developed simultaneously, and in an iterative manner. The initial sustainability criteria and literature and document review informed the data collection and site visits, which in turn informed further iterations of criteria specification and assessment. Finally, both the

Table 2
Sustainability assessment criteria.

Socio-ecological system integrity
Water and wastewater management
- Does the mill practice proper water management and work within the regulatory and ecological limits of the watershed?
- Does the mill treat its wastewater to an acceptable quality?

Residue and waste management
- Is the waste generated in the activities of the mill minimized and are unavoidable residues treated or disposed of properly?

Biodiversity and ecological integrity
- Are appropriate steps taken to evaluate and protect the biodiversity and ecological integrity of the watershed (e.g. improving the connectivity of natural ecosystems and protecting wildlife), including lands outside of protected areas in the watershed?
- Are the adverse cumulative impacts of monoculture on biodiversity appropriately managed?
- Are economically viable alternatives for more ecologically appropriate sugarcane production fostered?

Sugarcane straw burning for harvesting
- Is the mill burning the sugarcane straw in the fields? Has the practice of sugarcane straw burning in the watershed been controlled, especially to minimize adverse impacts in the vicinity of protected areas and urban areas?
- Does São Paulo have a feasible plan for eliminating sugarcane straw burning?

Air pollution
- Are air emissions from the mill properly evaluated, mitigated, controlled and treated?

Land use change
- Does sugarcane production maintain sufficient land for forests and other agricultural and food crops?

Socio-economic resilience
- Is sufficient socio-economic resilience being maintained for future generations (e.g. diversity of economic activities, maintenance of the local resource base, protection of local sources for food, water and other livelihood essentials, and encouragement of innovation and experimentation)?

Effects on soil quality and maintenance
- Is long-term soil fertility being evaluated and maintained?

Livelihood sufficiency and opportunity
Employment opportunities
- Does the company prioritize local labour?
- Are training opportunities for alternative employment available for all company workers (esp. cane cutters affected by mechanization)?
- Are company workers paid in a fair and transparent manner?

Quality of employment and safety
- Do company employees enjoy safe and healthy working and living conditions?
- Does the company respect worker rights and build positive worker–management relationships?

Community and regional development
- Does the company contribute to the surrounding community for education, culture and capacity building?
- Do the municipality and region have sufficient capacity to accommodate migrant sugarcane cutters (e.g. housing and other facilities) during harvest?
- Does the company enhance local economic opportunities and economic diversity (e.g. economic spinoffs)?
- Do the company's activities respect (eco)tourism activities of the region (visual impact, water quality, air pollution)?

National sovereignty
- Does sugarcane ethanol production serve to benefit all citizens (e.g. reducing import dependence)?

Intragenerational equity
Distribution of benefits and risks
- Are the benefits and risks generated by the presence of the company distributed equitably within local municipalities?

Interference in food production
- Will current and future sugarcane production respect other agricultural activities and avoid the replacement of food crops for energy production?

Intergenerational equity
Long-term ecological integrity
- Is sufficient biophysical and ecological integrity being maintained for future generations at all scales (esp. soil fertility, crop diversity, forest cover)?
- Does sugarcane production maintain soil quality well enough to allow sugarcane to be replaced by other crops in the future?

Economic resilience
- Is sufficient economic resilience being maintained for future generations (e.g. economic diversity, maintenance of the local resource base, protection of local sources for food, water and other livelihood essentials, encouragement of innovation and experimentation)?

Maintenance of culture and local knowledge
- Are traditional cultures and ways of knowing and local knowledge systems protected nationally (e.g. farming skills, local ecological knowledge, unique products)?

Resource maintenance and efficiency
Ecological efficiency of production
- Does the company seek cleaner production technologies?
- Has the company adopted more sustainable agricultural practices (soil conservation, biological pest control, green cane harvesting, non-chemical control of weeds)?
- Does the company maximize use of its resources and capacities through co- and by-production (e.g. multiple uses of residues for heat, power, liquid fuel, and soil amendment)?

Soil fertility
- Is soil fertility maintained and enhanced on the company's land (both owned and administered)?

GHG impacts
- Are GHG emissions and direct and indirect fossil energy use evaluated and minimized along the company's entire ethanol production chain, within an appropriate degree of certainty?

Perverse effects (efficiency paradox)
- Does ethanol production encourage automotive usage at any scale?
- Does increased ethanol production increase overall energy usage at any scale?

Social-ecological civility and democratic governance
Local governance
- Does the company contribute to and foster local good governance (e.g. participation in decision making, partnerships in initiatives)?
- Does the company contribute fairly to the costs of infrastructure and resources consumed that are shared with the community (e.g. schools, roads)?

Federal and state governance
- Do national regulations for the sugar-energy sector consider sustainability aspects, including transparency, participation of civil society and long term planning?

Corporate management
- Does decision-making within the company include all relevant stakeholders?
- Does the company sufficiently consider sustainability in its decisions?

Table 2 (*Continued*)

Distribution of risks
• Are the risks presented by the company equitably distributed (e.g. among communities, genders and social groups), recognizing that some people have less capacity than others to accommodate increased risk?
Enhancement of learning
• Does the company help to build deeper and more widely shared understanding of local sustainability issues?
• Does the company provide opportunities for discussions and experience in collective decision making?
International awareness
• Does international attention and scrutiny promote positive dialogue and practice in the sugar-energy sector and for this company in particular?
Prudence, precaution and adaptation
Uncertainty and adaptation
• Is the company sufficiently resilient in the face of change and surprise (e.g. multiple products, modular components, market alternatives, administrative flexibility and learning capacity)?
• Does the company promote the adaptive capacities of the region and reduce local vulnerability to external dynamics (e.g., extreme weather events, economic disturbances)
Data limitations
• Are key areas of uncertainty in environmental management being addressed at all levels (e.g. water resources, sugarcane straw burning, GHG emissions)?
• Is sufficient and timely information being shared between the various stakeholders (governments, mills, NGOs, citizen groups, international organizations) to promote informed decision-making?
Immediate and long-term integration
Promoting collective visioning and action
• Are appropriate and collaborative steps being taken by stakeholders at all levels to ensure the challenges and opportunities of sugarcane ethanol are addressed in an integrated manner (including the specification of desired short- and long-term goals)?
• Are tradeoffs amongst alternative options discussed and assessed in a sufficiently inclusive and informed manner, and designed in a way that do not displace significant adverse effects to future generations?
Promoting positive synergy
• Can the expansion of sugarcane positively influence other agricultural sectors at all scales (e.g. increased international attention)?
• Can positive actions undertaken by the company serve as a means of improving social-ecological outcomes, and promote better practices by other companies (both sugarcane-ethanol based, and otherwise)?

criteria set proposed in Table 2, and the observations outlined in Table 3 were revised in accordance with comments from key stakeholders, including the mill and the municipality.

The context-specified criteria provided in Table 2, and initial indicators provided in Table 3 provide a package to help identify the key strengths and limitations of ethanol production at multiple scales, and elaborate means by which ethanol could make more consistently positive contributions to sustainability of Brazil, São Paulo state, and the sugarcane production region. The criteria are contestable, both in terms of whether or not they in fact represent the full set of important desirable characteristics, as well as how these characteristics may be actualized for the given context. We believe one benefit of undertaking a sustainability assessment is that it serves to promote more open and constructive dialogue about what is considered important and desirable.

5. Observations regarding the sustainability criteria

As noted above, the case specific sustainability criteria provided in Table 2 were initially addressed in a set of observations of the case and context presented in Table 3. The observations draw from a wide variety of quantitative and qualitative indicators, and provide an initial analysis of the most significant considerations relating to the sugarcane-ethanol mill in its broader context. Throughout the iterations between criteria and observations, care was taken to ensure all the generic sustainability assessment criteria were addressed in the case specific context.

As previously noted, the observations were revised in accordance with comments by the mill and representatives from the municipal government. Both the sustainability criteria and the observations were well received. It is notable that the representatives from municipal government favoured quantitative indicators, and all attempts were made to provide such indicators in the observations. However, in order to protect the confidentiality of the mill – which was an initial requirement for participation – some indicators may only be presented in a qualitative manner. Ideally, future assessments may proceed with greater disclosure, while ensuring the mills are not harmed in the process, but rather benefit from the opportunity to improve their operations.

For each consideration in Table 3, the contributions to sustainability are ranked on a simple three-point scale, identifying potential positive impact (+), potential negative impact (−), and potential impacts that may be mixed, or positive or negative depending on how the project is undertaken (=). The purpose of ranking is not to sum up all the positive and negative indicators in a quantitative test, but rather to gain broad insights into areas of strengths and weakness, and associated openings for improving contributions to sustainability. Furthermore, to illustrate the importance of cross-scale interactions more explicitly, Table 3 provides a column detailing at what scales the interactions occur, recognizing that this process is imperfect, in that it attempts to simplify complex dynamics. The legend is as follows: M – Mill; C – Community; W – Watershed, region; S – São Paulo; B – Brazil; I – International; ALL – All scales (i.e. no particular scale).

6. Discussion

The observations provided in Table 3 reveal that this sugarcane ethanol operation and its broader context have a wide range of positive and negative effects, many areas of potential improvement, serious pitfalls to avoid and uncertainties to address. While not every important theme can be discussed in the limited space, we will elaborate on some key issues that emerged during the assessment: (1) long-term water availability and water quality maintenance; (2) biodiversity enhancement and reversal of ecological fragmentation; (3) the elimination of sugarcane straw burning and increasing mechanization; (4) indirect and direct land-use change; and (5) the quality and availability of livelihood opportunities. These five issues were proposed by the research team and approved by various stakeholders, including mill management and government environmental officers. Furthermore, we propose these issues as priority issues for broader national strategy relating to sugarcane-ethanol production. The five issues are first discussed at the strategic level, as they all have strategic level implications and cumulative impacts. Following that, the issues will be grounded in the local context of the mill as part of a brief discussion on the potential benefits of collaborative partnerships at the municipal level. Finally, it is worth noting that the more direct impacts of the mill, both positive and negative, discussed in the observations

Table 3
Initial observations and indicators from sustainability assessment of the sugarcane-ethanol mill in São Paulo state, Brazil.

Socio-ecological system integrity		
Water and wastewater management		
• The mill collects surface and ground water, and water usage is monitored. Regional licence data are not easily accessible, and there are reports of several small producers that collect water illegally. None of the interviewed actors had been audited in recent years regarding water consumption.	M	=
• Water consumption and the effects (including cumulative) of diffuse water pollution (e.g. fertilizer and soil runoff) at the regional level are insufficiently monitored, and the resulting uncertainty hinders proper long-term planning.	W	=
• Net water consumption at the mill is between 0.7 and 0.8 m^3 per ton sugarcane processed, which compares favourably to other mills. Further conservation is possible through improved irrigation, increased reuse of process water, and novel techniques (e.g. mechanical harvest permits washless sugarcane processing). Most water is returned to the watershed as treated wastewater or during ferti-irrigation with some evaporation losses during ferti-irrigation and in the cooling towers.	MW	+
• The mill's sewage is treated in a combination of a septic tank/filter and a compact sewage treatment plant with high percentage treatment efficiency, meeting government requirements.	M	+
• The mill's industrial wastewater is treated in treatment ponds. When pond capacity is exceeded, excess water is released into nearby freshwater in accordance with legislation. The mill is planning to construct a more efficient sewage treatment plant to better handle industrial wastewater.	M	=
• Where improper handling of stillage in ferti-irrigation occurs, it damages soil and contaminates rivers and groundwater, and is already occurring in some sugarcane operations.	MW	–
Residue and waste management		
• Brazilian sugarcane operations generally have effective organic material handling. In the studied mill: stillage, filter cake, and waste from septic tank are used to ferti-irrigate sugarcane plantation and riparian forests; bagasse is used for steam generation or stored for anticipated future power generation; and straw (when not burned) is left in fields for soil protection.	MB	+
• Improper handling of organic and inorganic substances (e.g. fertilizer, lime, pesticides, filter cake, stillage and ash from bagasse burning) can harm soil and water (e.g. eutrophication of waterways).	All	=
• Hazardous wastes (e.g. oils, greases, agrochemical packaging) are treated and disposed according to legislation.	M	+
• The recyclables are donated to an educational institution, which then sells them to fund programs.	ML	+
Biodiversity and ecological integrity		
• Since 2009 the company has recovered 65 ha of Permanent Preservation Areas[a], with a further 60 ha committed for recovery and currently under mapping. Part of this recovery was required by government, but also represents a proactive stance by the company. Some of the recovered area is on land administered by the company, which is notable because most sugarcane companies only recover their own land (despite approximately 80 percent of sugarcane coming from administered land).	ML	+
• As part of its environmental system, the company is developing a Legal Reserve (protected area) in neighbouring areas indicated by the environmental agency. In this case, the Legal Reserve area is equal to twenty percent of the total area of the mill.	ML	=
• The mill managers are studying areas to create a private protected area to be managed by regional stakeholders.	ML	+
• The lack of historical data on species richness in the region makes it difficult to assess the impact on biodiversity caused by the expansion of crops in the region occurred in recent years. The mill is in the final stages of preparation of an Environmental Impact Statement that will include a broad survey of flora and fauna throughout the region, and then they will start a program for monitoring fauna.	W	–
• Land fragmentation is a serious threat to biodiversity conservation. Priority Areas for Biodiversity Conservation are considered during environmental licensing in São Paulo (Joly et al., 2010). The mill's land is located primarily in high priority areas that require ecological corridors to link native vegetation.	S	=
• Due to competition pressures, sugarcane mills do not reveal where they intend to expand sugarcane plantations, and this secrecy limits the environmental licensing process and land-use change assessment.	W	–
• Brazilian research indicates smaller units of ethanol production based on agroforestry and organic practices can contribute to greater biological diversity and reduce environmental impacts (Lombardi et al., 2009). However, such alternative forms of production have no competitive economic advantage and require government support for its implementation.	All	=
Burning of straw		
• Sugarcane straw is burned on forty percent of harvested area, although the practice has been controlled to minimize impacts to the vicinity of protected areas (Avolio, 2002; Ometto et al., 2009; Ribeiro, 2008). Straw burning harms humans, flora, fauna and water resources.	M	–
• The mill has signed the Agro-Environmental Protocol, a state government initiative that aims to eliminate straw burning in areas with slopes less than 12 percent (suitable for mechanization) by 2014, and all land by 2017. To do so, leased areas with slopes greater than 12 percent will be returned to their owners, and the mill will expand into areas suitable for mechanized cutting. Elimination of straw burning will reduce both the ecological and health problems, and water usage in the processing step. The mill plans to achieve 85 percent mechanical harvesting by 2017, and 15 percent of manual harvesting without burning, carried out with new sugarcane cultivars with lower and softer straw content to facilitate manual cutting. It is not certain what land the mill will expand onto.	MWS	=
• Forty percent of the mill's sugarcane is grown in a loosely protected area (similar to IUCN Category V), where sugarcane plantations are allowed but straw burning is forbidden. The mill is still burning sugarcane straw there. The protected area committee is attempting to prevent the burning, while the mill is challenging the legitimacy of the protected area. The conflict is under negotiation.	M	–
• There is currently disagreement regarding burning regulation. Burning is banned within 1 km from urban centres, and local stakeholders and government want to enlarge the radius to 3 km, which the sugarcane industry challenges. In the past four years, there have been two occurrences of burning less than 1 km from urban areas.	ML	–
Air pollution		
• Air emissions at the industrial plant of the mill conform to regulations.	M	+
• The region in which the mill is located is becoming ozone saturated (a precursor to smog). The emissions of NO_x from the mill lead to tropospheric ozone (an atmospheric pollutant). This current saturation may limit future regional expansion in ethanol production. The environmental agency is attempting to restrict electricity production from straw due to smog concerns, which reduces profitability of sugarcane.	W	–
• While emissions due to straw burning are not treated, the timing of burning is planned to avoid plume formation over urban centres, and conforms to regulation.	LW	=
Land use change		
• Sugarcane is replacing diseased orange crops as an approach to disease control, with a subsequent decrease in pesticide application.	L	=
• Regional direct and indirect land use changes due to sugarcane ethanol are both uncertain and contested.	B	=
• At the behest of the environment agency, the mill recently removed sugarcane crops under cultivation in a Permanent Protected Area (where agriculture is forbidden), and the land is becoming re-naturalized. It is notable that the sugarcane had been in the protected area for 30 years, implying a long history of inappropriate monitoring and enforcement by government now being corrected.	M	=

Table 3 (*Continued*)

Livelihood sufficiency and opportunity		
Employment opportunities		
• The increase in mechanized harvest eliminates cane-cutting jobs while providing employment to more qualified workers (e.g. machinery operation). Recent plant expansion has maintained overall level of employment but changed employment demographics. The company offers retraining programs for all employees, to enable mobility towards more qualified positions. The company established intensive training in the off-season and also extensive training during the harvest, releasing staff to attend day classes and taking exams. Cane cutters who are illiterate or lack driver's licences (i.e. the more vulnerable) are less likely to be retrained.	M	=
• The total loss of jobs due to the elimination of manual cane harvesting represents a pool of unemployed workers that is too large to be absorbed by the sugarcane sector. Other economic sectors such as construction have absorbed part of the workforce (Mello, 2011).	B	+
• The company prioritizes local labour, but has difficulty in finding candidates for many positions, because local residents lack qualification or prefer work in other areas (e.g. tourism).	ML	–
• The private sector of Brazil bears the cost for much staff training due to a lack of trained professionals and deficiencies in the Brazilian educational system.	B	–
Quality of employment and safety		
• In 2009 the mill implemented a Health and Safety Action Plan to reduce accidents in the field and industry. The Plan includes better equipment and improved monitoring, and reduced accidents by 54 percent during the last harvest, even accounting for expanded production.	M	+
• The cane cutters perform gymnastics every day before the start of the workday.	M	+
• Migrant workers receive routine inspections of their housing quality (e.g. treated water and sewage collection), daily transportation to the field, and return transportation back home after the harvest.	M	=
• According to the mill, harvesters are paid a fixed income plus a bonus for cane cut, in a manner that is considered transparent. This reduce problems of exhaustion, as the additional cane cut is not as high as in payment systems based only on production (Alves, 2008).	M	+
• In the last six years the mill received one fine for breaking an agreement on the limitation of working hours. The fine was paid as a donation to the community. The company is supervised monthly, and currently is meeting all the requirements.	M	=
Community development		
• Of the 900 cutters 500 are migrants and are installed in non-permanent settlements, thereby creating the potential for social tensions due to seasonal population movement.	MLSB	–
• The mill provides kindergarten for children of employees with remaining vacancies filled by the municipal population. The company also has a program to encourage sports for teenagers.	L	+
• The mill has a project to collect used oil in the city, and also a partnership for proper disposal of fluorescent lamps generated by the municipal government.	L	+
• The mill organizes environmental education activities and provides learning material for primary schools in the neighbouring counties, as well as general environmental information available to residents.	LW	+
• There is a partnership between the mill and municipal government to maintain a seedling nursery, which provides seedlings to the public and for reforestation projects.	LW	+
Impact on other economic activities		
• Trucks transporting cane use the same highways as vehicles used by ecotourism lodges, potentially creating a nuisance during the tourist season. The smoke and ash from straw burning and the odour of stillage[b] applications are considered a nuisance to tourists.	L	–
• Tourism entrepreneurs and mill managers maintain a dialogue to find ways for mutual benefit. The mill avoids application of stillage and burning during high tourist season and informs the inn prior to application.	L	+
Regional and local economy		
• The mill generates economic spinoffs (e.g., the company that handles the hazardous wastes and the provisioning of local services for neighbouring cities) (Martinelli et al., 2011).	L	+
• The company contributes to the development of local economy, and its tax contribution represents nearly half of total revenues received by City Hall.	L	+
Intragenerational equity		
Distribution of benefits and risks		
• The mill prioritizes hiring local labour, which can promote local employment and improve regional development.	L	+
• The mill directs its social and environmental programs to the surrounding municipalities benefiting the local population.	LW	+
• The large influx of migrant workers helps spread economic benefits farther, but creates social problems in the sending and receiving communities.	B	=
• The most direct health impacts on communities result from the smoke and ash released during sugarcane straw burning, which cause respiratory ailments in children, asthmatics, and elderly people, and increase the burden of health care on public services and families (Ribeiro, 2008).	LW	–
Interference in food production		
• The impacts of sugarcane ethanol on food production (and land use change more broadly) remain contested.	I	=
Intergenerational equity		
Long-term environmental impacts		
• Due to regulations that trade off ecological for economic considerations, compliance with environmental legislation does not ensure long-term ecological integrity. Furthermore, the quality of ecological monitoring and evaluation is insufficient to determine long-term trends.	B	–
• The impact of ethanol on GHG emissions depends greatly on land use change, which remains contested and uncertain (Sparovek et al., 2009; Lapola et al., 2010; Pacca and Moreira, 2009). The mill lacks a Greenhouse Gas Inventory.	M	=
• Soil testing is performed in the fields associated with the plant with the objective of maintaining soil quality, and ensuring long-term productivity.	M	+
Economic resilience		
• There is ongoing research into transforming old sugar and ethanol mills into biorefineries capable of producing a wide range of products so as to increase economic resilience (assuming climatic conditions remain favourable). The mill is investing in product diversification.	MI	+
• The economy of São Paulo is diversified, and it is not expected to become overly dependent on ethanol and sugarcane (IBGE, 2009).	S	+
Maintenance of culture and local knowledge		
• The impact (if any) of the mill and ethanol production on local traditional cultures and ways of knowing was not identified.	ML	=
Resource maintenance and efficiency		
Ecological efficiency of production		
• The mill is investing in cleaner production technologies (esp. reduce emissions, improve wastewater treatment, and reduce water consumption).	M	+
• Farming practices include precision agriculture for application of gypsum to correct soil acidity; organic and chemical fertilizers; herbicides, pesticides and maturing within the limits defined in national legislation. There is limited organic sugarcane production, and the product is limited to sugar.	M	=

Table 3 (*Continued*)

• The region in which the mill is located is considered saturated with ozone (a precursor to smog). The emissions of NO_x from the mill lead to further ozone production and ultimately smog and poor air quality. This current saturation may limit future regional expansion in ethanol production, as well as electricity production from bagasse.	MW	–
• The mill is diversifying their sugarcane products (including sugar and hydrated ethanol).	M	+
Soil fertility		
• The mill has measures to promote soil conservation (e.g. straw to protect soil from wind and water erosion, terracing to reduce volume and velocity of runoff, and rotation with peanuts).	M	+
• Soil loss is not measured and some of the agrochemicals used have not been tested for local conditions and their ecotoxicity remains uncertain.	MLW	–
GHG impacts		
• The plant lacks a GHG inventory to determine the carbon balance of its production process.	M	–
• Sugarcane ethanol production is still highly dependent on fossil fuels for the acquisition and transportation of inputs, operating machines, and chemical fertilizers. While it is possible to produce diesel from sugarcane, current costs are prohibitive.	B	–
Perverse effects (efficiency paradox)		
• The low cost of ethanol encourages car usage, and when coupled with government policies that support the automotive industry, both emissions (including GHGs) and traffic have increased.	S	–
• Combustion technology in cars has not improved in recent years.	All	–
Social-ecological civility and democratic governance		
Local governance		
• The mill is the largest company in municipality in employment and tax revenue, and may influence municipal decisions.	L	=
• Municipal public authorities are empowered only to supervise and enforce environmental standards defined by state government and environmental agencies. The municipality exercised its power by extending the required riparian buffer zone from 30 to 50 m along the main river of the city. This buffer expansion was both to help maintain water quality and to make the river more enjoyable for tourists (who raft on the river), and has been considered as one successful means of managing sugarcane production.	L	+
• The mill is represented on municipal advisory councils on environmental, tourism and rural development, which promotes regional dialogue to address sugarcane-related problems, and tries to foster collective action and partnerships.	L	+
Federal and state governance		
• The environmental licensing process in São Paulo state tailors licensing rules based on the size and the location of the mill (e.g., an agri-environmental zoning being considered at the state level will be context sensitive).	S	+
• In order to improve good practice in the industry, the state government has developed the Agri-Environmental Protocol, a voluntary partnership between the departments of environment and agriculture and industry representatives. The agreement has high adherence of the mills, has increased mechanized harvest from 34 percent in 2007 to 55 percent in 2011, and aims to recover 265,000 ha of riparian vegetation by 2014 (SMA, 2011).	S	+
• There is no government regulation of the maximum area of sugarcane crops in São Paulo, and crop area is largely dependent on market dynamics.	S	=
• The Federal Government has developed an inter-ministerial agreement that includes dialogue with industry and rural worker representatives. The agreement is generally regarded positively by the agrarian and land reform movements, although monitoring has not yet begun, and some of the signatory mills have been recently fined for using slave labour (CONTAG, 2009; Scolese and Iglesias, 2009). The mill related to this research is not yet a signatory.	BM	=
Corporate management		
• The mill was originally family run until the 2008 global financial crisis, at which point the owners sold a part of the company and hired professionals to the company's senior management. The change in the board brought attention to environmental management, work safety, and improved community relations.	M	+
• The current mill board has created a Sustainability Committee, with monthly meetings among senior and technical managers to discuss sustainability issues (e.g. environmentally friendly technologies, and social and environmental programmes).	M	+
International awareness		
• The interest of other countries in buying sugarcane ethanol may promote better practices in Brazil (both social and ecological) through non-tariff barriers such as certification; although excessive growth of demand may overwhelm capacity for monitoring.	All	+
• The company has customers who make broad and rigorous audits in order to follow international standards, thereby pushing the mill to raise its quality standards above the legal requirements.	All	+
Prudence, precaution and adaptation		
Adaptation		
• To promote adaptation, the industry has diversified its production and has invested in technology for the development of new products derived from sugarcane: bio-electricity, green plastics, biodiesel, diesel and hydrocarbons of low carbon.	M	+
• The mill can quickly respond to changing market prices for sugar and ethanol by changing the final product.	M	+
• Sugarcane production is climate sensitive. Drought (e.g. 2010) and excess rainfall (e.g. 2009) reduce productivity and cause shortages in the domestic market.	All	–
Uncertainty and data limitations		
• Indirect land use change is still a critical uncertainty. Conflicting scientific research is inadequate to support policy making, and regulation is lacking (e.g. the mill's anticipated expansion of sugarcane crops will not require any study of indirect land-use change).	M, All	–
• Cumulative impacts of sugarcane monocrops, especially effects on biodiversity, have not been studied enough.	B	–
• Notable data limitations include the impact of diffuse pollution (from agricultural inputs and eroded soil) on water bodies, the maintenance of biodiversity, GHG emissions, and long-term groundwater availability in the watershed. The São Paulo environmental agency is expected to increase data collection, although care is needed to ensure data are representative and the proper indicators are chosen. Furthermore, it is important for the municipality to invest in local monitoring to aid decision-making and outcomes.	S	–
• There is no available information about the energy return on investment (EROI) of sugarcane by region, although the general EROI for sugarcane ethanol is considered favourable compared to most biofuels (Giampietro and Mayumi, 2009). How the EROI will change with mechanization was not found.	S	=
• The rapid expansion of sugarcane plantation in the Tiete-Jacaré Watershed has not been monitored and the impacts are difficult to measure.	W	–
• Lack of accurate data for lifecycle assessments limits certainty in any overall analysis of the production chain, requiring on-going research and adaptive management on the part of all stakeholders.	M	–
• The company is conducting an Environmental Impact Statement as part of the requirements for acquiring environmental licensing to expand its production. The company is also planning to develop a Sustainability Report using GRI guidelines, and apply the Ethos Indicators of Corporate Social Responsibility, which can improve planning and increase transparency.	MLW	+

Table 3 (*Continued*)

Immediate and long-term integration		
Promoting collective visioning and action		
• The regulation of activities of all the mills needs better knowledge of carrying capacity and cumulative effects (esp. on water and biodiversity) to ensure long-term benefits for the region. To this end it will be necessary to expand and integrate the existing environmental and social information, in order to overcome data limitations and be prepared to deal with uncertainties. This issue demands collaboration (esp. involving government, industries, agriculture, university and civil society organizations).	ALL	=
• Many important decisions (e.g. watershed management, policies that increase energy usage through low-cost ethanol, regulating agricultural practices, and biodiversity management) are made at the state and federal government levels and may neglect local and regional factors (e.g. the importance of ensuring desirable local ways of knowing and living are not harmed).	B	=
Promoting positive synergy		
• The sugarcane industry may be a good means of seeking improvements in other Brazilian agriculture sectors in a manner that respects natural limits, promotes good governance, and improves both quality of life and employment at local level. Newly advanced benchmarks and good agriculture practices can result in mutually reinforcing and lasting benefit.	BI	+
• The municipality may benefit by developing qualified professionals in a way that the local population receives the benefits and the company avoids hiring employees from distant cities.	ML	=
• If properly undertaken, Brazil could be a model for other nations on how to develop sustainable fuels.	MB	+
• The actions of corporate social responsibility can contribute to regional development and improved quality of life. To this end, the company needs to continually improve social programs and employee training, evaluate the quality of its initiatives and dialogue with the local population. Likewise, the municipality must be proactive and willing to invest in the future.	ML	=
• The mill can enhance its framework for action from the generation of more environmental information and links with other regional players to increase protection of animal species and protected areas, share information about water and soil quality and invest more in monitoring, cooperate in designing training for alternative employment, demonstrate how best to integrate stakeholders in decision making, etc.	MLW	+

[a] Under Brazilian law, the Permanent Preservation Areas (APP) are composed of belts of forest that are found on the edges of rivers, lakes and lagoons, hill-tops and slopes, and other environmentally sensitive areas which are essential to the preservation of water resources, scenery, health of animals and plants, biodiversity, soil, and the health of human populations in the area; they are mandatory on public and private lands.

[b] Stillage (or vinasse) is "the residue grain from the manufacture of alcohol from grain" (McGraw-Hill Science and Technology Dictionary).

and indicators shown in Table 3, provide the mill's sustainability committee with a comprehensive framework for exploring opportunities for improvement. To this end, the assessment process provides both strategic and practical insights for progress towards sustainability.

6.1. Key strategic issues in sugarcane ethanol assessment

This section will briefly elaborate on the five issues noted above. These issues are all embedded in the social-ecological context of Brazil and influence one another as well. As the discussion highlights, addressing any one of these issues requires integration across sectors and scales.

6.1.1. Water, biodiversity and land use change

At local to national levels, sugarcane ethanol is engendering important ecological problems. Water is an important concern for agriculture in Brazil, in terms of freshwater availability and quality. The continued availability of water for sugarcane processing is subject to future freshwater supply, and the changing consumption patterns of municipalities and industry. As was previously noted, the watershed of the mill under investigation is approaching regulatory thresholds. At some point water rationing may become necessary, and the ethanol mills may be required to increase water efficiency simply to maintain current levels of production. One means of addressing water usage related to sugarcane production is through agri-environmental zoning, which can set targets and limits to consumption, but requires much more stringent monitoring and enforcement.

Concerning water quality, there is relatively poor knowledge of non-point-source pollution (e.g., agricultural inputs and soil runoff) and its impacts on waterways and human health. The state environmental agency is expanding monitoring points for surface and ground water (as well as air and soil), and the indicators are periodically evaluated so as to provide a general understanding of the current situation. Monitoring is to be more concentrated in areas that experience higher levels of pollution. While the state monitoring system provides general baseline data, the data must be enriched through separate monitoring programs at the municipal and watershed levels. Local monitoring programs can provide finer detail on specific concerns not addressed by the state agencies, and may also supplement areas that are poorly monitored by the state (because they are less polluted). The water quality data for our case specific watershed are considered insufficient to support decision-making, in part because the watershed is not in a state priority area given that pollution levels are below thresholds, and local monitoring has not addressed the data limitations.

Biodiversity is another area of concern that requires a regional and strategic approach. While the mill complies with the legal requirements, successful enhancement of biodiversity is an issue of regional connectivity and cumulative effects, which result from the mosaic of monocultures and protected areas. The characteristics of sugarcane plantations themselves also undermine biodiversity due to a number of factors: monoculture leads to low diversity of organisms; sugarcane plants have a low physiognomic and floristic similarity with the natural habitat of forest or savannah; pesticides and burning harm flora and fauna; and isolated trees are suppressed to facilitate mechanization (von Glehn, 2008). Durigan (2010) argues a paradigm shift is needed to better recognize that while conservation has individual costs, it is of collective interest and therefore should be supported fairly on private land. The economic incentives for protection of remnant vegetation and restoration of areas relevant to biodiversity conservation on private lands are urgent, and need to be implemented in Brazil.

Biodiversity depends strongly upon land use, and the watershed in which the mill is located is experiencing tremendous land fragmentation, as more than 95 percent of vegetation fragments are smaller than 100 ha, which worsens the isolation of populations of plants and animals and threatens genetic diversity. As noted in Table 3, there is general uncertainty regarding the land-use impacts of sugarcane ethanol, in part because Brazilian environmental impact statements do not monitor several aspects of land-use change, including crop substitution and land fragmentation (da Costa, 2008), and are limited by the culture of secrecy among ethanol mills surrounding future land developments, because such knowledge is of strategic economic value. Finally, as will be discussed below, the expansion of mechanical harvesting will result in sugarcane crop displacement, as mechanized harvesting cannot take place on highly sloped land.

6.1.2. Straw burning, mechanization and employment rights and opportunities

The elimination of straw burning in the fields, which should be nearly complete by 2017, is expected to have several impacts worth considering. There are obvious benefits to eliminating burning, particularly in terms of air quality and health, as straw burning is a major source of local air pollution and releases carcinogens. Furthermore, straw burning is a nuisance to tourists and undermines the ecotourism sector in the region of our mill. Eliminating straw burning may allow for more residues to remain on the field, which benefit soil fertility. Alternatively, the straw may be used for electricity production and even second-generation (cellulosic) ethanol production.

Despite noted benefits, the elimination of straw burning will entail other consequences. The impacts of mechanical harvesting on the energy return on investment (EROI) of ethanol production is uncertain, although experience with corn ethanol indicates that mechanization may lower EROI (Giampietro and Mayumi, 2009, chapter 7). Switching to mechanical harvesting would entail land-use change because mechanization requires abandoning steep-sloped land (greater than 12 percent grade). Land-use change is a central concern in sugarcane ethanol assessment in Brazil (Lapola et al., 2010). If properly undertaken, the transfer between steep- and shallow-sloped land may promote greater crop diversity and enhance ecological connectivity, although this requires analysis beyond what is provided herein. The mill under investigation has considered maintaining some portion of the steep land and harvesting it with manual labour beyond the 2017 deadline. It is also important to note that decisions are highly influenced by economic and financial considerations, which are quite dynamic and dependent upon world market signals.

The mechanization of sugarcane ethanol will also impact employment patterns and the sugarcane agroindustry sector will continue to change its worker profiles in coming years. While mechanical harvesting requires more specialized work, it removes a source of employment that is relied upon by many workers (including migrants), especially those who lack the minimum requirements to participate in the retraining programs. While other sectors of Brazil have been able to absorb some of the labour, notably the construction sector, there are seemingly insufficient alternative livelihood opportunities for these displaced workers. Furthermore, the most vulnerable workers are likely those who lack basic skills, such as literacy, that are necessary to secure other employment. At the same time, mechanized harvesting will eliminate many of the jobs for which the ethanol sector has been criticized internationally, notably with regard to labour conditions and the impacts of and on migrant labour (Nuffield, 2011; Martinelli and Filoso, 2008).

In sum, mechanization will not be without benefits and drawbacks, and despite being fundamental to environmental protection, it is inevitable that mechanization will create different winners and losers. Ideally, whatever changes to agricultural practices that occur should take place with some idea of what the desirable end goals are, and how best they may be achieved.

6.2. The local context – the need for collaborative partnership

The five issues discussed above all relate to the context of the mill under investigation, and in certain instances the mill has responded in a progressive manner. First, the mill is investing in technology to decrease water consumption and improve treatment, and is restoring sensitive ecological areas and will soon implement fauna monitoring and establish ecological corridors of riparian vegetation. As for eliminating straw burning, the mill will follow the planned phase-out of straw burning by 2017, and this can be considered positive for environment, public health and ecotourism reasons noted above. In terms of land use change, the mill has prioritized expanding into land that previously grew diseased oranges. To address worker rights and safety, recent mill programs have resulted in reduced accidents, and improved work safety. The mill also offers retraining programs for displaced workers although it is uncertain how successful the retraining programs are at reaching the most vulnerable (for this particular mill and in general). Finally, the mill is also in the process of improving its environmental and social monitoring through initiatives that include Global Reporting Initiative Sustainability Reporting, Ethos Indicators of Corporate Social Responsibility, Bonsucro Certification and ISO 22000.

Despite the efforts by the mill regarding the issues described above among others, achieving significant positive gains requires collaborative partnership at the community and regional levels and strict limits on the negative impacts. For example, to ensure positive water benefits, the local government must identify the priority concerns, such as soil runoff into the rivers used for ecotourism. Similarly, without a regional plan for improving ecological connectivity, the benefits of the mill's individual efforts will be diminished. Likewise, the government must also be involved in providing new employment and training opportunities for displaced workers. Responsibility for better practice and outcomes must be widely shared.

There appears to be tremendous potential for the mill and local government to develop joint strategic water, biodiversity, and capacity building initiatives, and dialogue is already taking place. To participate more effectively in regional governance, the mill sends representatives to municipal councils, and has initiated dialogue with the regional tourism association to help resolve conflicts between sugarcane production and tourism. Furthermore, as was noted in Table 3, the mill and the community collaborate on social programs in education and sports, although there is recognition that procedures are necessary to evaluate effectiveness of the initiatives.

To ensure positive outcomes from collaborative partnership, it will be necessary to navigate both power dynamics and politics. The mill is a powerful stakeholder – as it is the largest employer and is responsible for approximately half of municipal tax revenue – and its favoured position implies that it may shape dialogue for its own interests and be a source of both positive and negative change, depending on how it interacts with local stakeholders and the environment. In these political actions, all stakeholders must ensure that any partnerships are sufficiently nonpartisan such that long-term plans survive changes to the municipal government.

7. Conclusion – towards more sustainable ethanol production

This paper applies a sustainability assessment framework to assess a sugarcane ethanol mill in São Paulo state, Brazil, seeking to identify opportunities for improvements towards sustainability. A sustainability-based strategic level assessment, such as the one described above, may serve well in guiding and informing an anticipatory and participatory planning program by helping to identify the broad objectives to be met, and providing a comprehensive framework with explicit criteria for comparative evaluation of the main options for fiscal, regulatory, planning and other means of managing the growth. The case described above demonstrates that important insights can be drawn by applying an assessment framework that covers the full range of sustainability issues and seeks integration across disciplines and scales. The research presented above ideally demonstrates both the importance of such kind of assessment and the unavoidable complexity inherent in the integration of things that matter. Sugarcane ethanol production is not good or bad in and of itself, but rather as a result of how it is undertaken.

The results of the assessment indicated that for the specific context at hand, important opportunities for improvement fall under five categories: (1) long-term water availability and water quality maintenance; (2) biodiversity enhancement and reversal of ecological fragmentation; (3) the elimination of sugarcane straw burning in the fields and increasing mechanization; (4) indirect and direct land-use change; and (5) the quality, availability and durability of livelihood opportunities. The five issues all require broader strategic planning, but must also be understood within the local context of the mill and its watershed. To address these issues requires long term integrated planning and monitoring, better understanding of cumulative impacts and thresholds, recognition of important tradeoffs, an enforcement of limits, and a credible and collaborative decision-making process that involves and empowers stakeholders to set the agendas and seek common goals. Furthermore, we propose these issues as priority issues for broader national strategy relating to sugarcane-ethanol production. Ultimately, important and difficult decisions must be made, decisions that will be simultaneously technical, economic, social and ethical. This work contributes to that broader conversation.

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