JOURNAL OF BIOMASS AND BIOENERGY

Assessing the relationship between sugarcane expansion and human development at the municipal level: a case study of Mato Grosso do Sul, Brazil.

1. Introduction

Globally, energy policy is driven by the confluence of energy security, climate politics and energy equity concerns. This energy trilemma has led to a shift towards alternative, renewable fuels, of which bioenergy and biofuels are an important energy source. Brazil is the world's second largest producer of ethanol [1,2] and, since the early 2000s, has undergone a rapid expansion in the area cultivated with sugarcane [3].

As a result of policy-driven demand and a growing domestic and international market, sugarcane cultivation in Brazil is expected to increase in the coming years [4]. This demand is likely to be met through a combination of cropland expansion and intensification in traditional production areas. At present, the Centre-South region of Brazil is responsible for around 90% of sugarcane production, with the state of São Paulo contributing around 54% [5]. However, rising land prices and strengthened environmental legislation in São Paulo state have led farmers and investors to seek new areas for sugarcane production. As a result, the Centre-West region (the states of Mato Grosso, Mato Grosso do Sul and Goiás, and Brasilia, the Federal Capital) has become an epicentre for sugarcane expansion in Brazil [6]. The expansion of sugarcane into these frontier states implies both positive and negative economic, social and land use change, for example related to (in)direct land use change, employment and agricultural production [7-10].

In terms of the social outcomes of sugarcane-based ethanol, in São Paulo studies have shown that sugarcane has both positive and negative impacts. For example, sugarcane has been shown to increase employment opportunities and municipal revenues (e.g. [5,10]), but to increase land prices and inflation [11,12]. However, much less is known about the relationship between socio-economic development and sugarcane activity in frontier regions. This understanding has become more important due to the rapid expansion of the sugarcane industry into these non-traditional sugarcane regions.

This paper has the following research aim: to examine the relationship between human development and the presence or absence of a sugar mill in the frontier state of Mato Grosso do Sul (MS). An important contribution of this paper is that it undertakes the analysis by municipality to arrive at a spatial understanding of how this relationship materialises over time. To address the research aim, the paper has the following research objectives, to: (1) identify municipalities with aptitude for sugarcane cultivation; (2) assess existing land use in each municipality; (3) develop a measure of human development at the municipal level in MS; and, (4) examine the relationship between human development at the municipal level and the presence or absence of a sugar mill in MS over time. The paper finds evidence that municipalities with a mill perform relatively better in terms of human development than those without, which echoes findings from other studies (e.g. [5,10,13]. However, it also finds that municipalities with mills already performed relatively better than those without. This suggests that siting decisions are based on more than just availability of land considered apt for sugarcane and that the impacts on human development are likely due to more than just the presence of sugarcane activities. This has implications for efforts to promote sustainable energy and agriculture, in particular it highlights the need for local and federal government to develop policy that prioritises local value capture and retention.

The rest of the paper is structured as follows: the next section begins with an overview of the Brazilian sugar-ethanol sector, its environmental and social impacts, and the socioeconomic and agricultural context in MS. Section 3 then provides a detailed description of the methodology, while Section 4 summarises the results. Section 5 summarises the major findings and discusses the implications of this research for sugarcane expansion areas. Finally, in Section 6 some concluding comments are made with respect to what this study might suggest for delivering human development in sugarcane expansion areas.

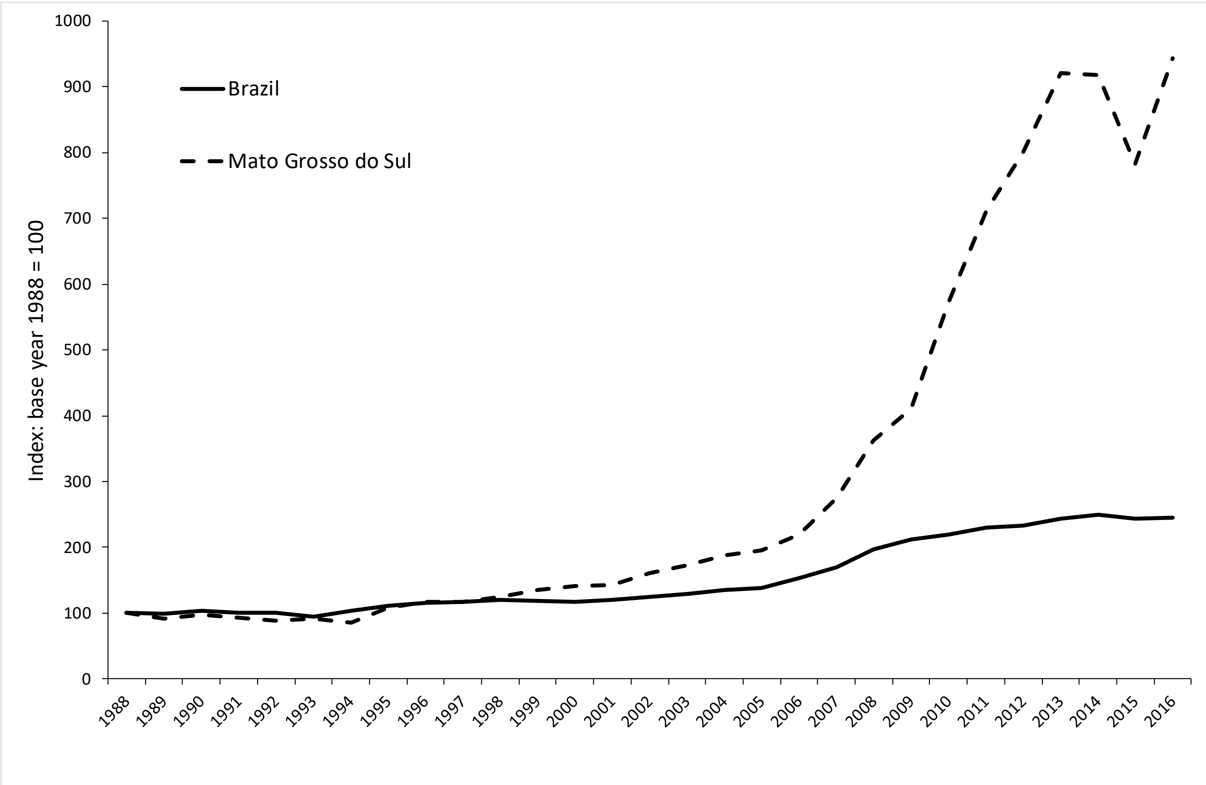
2. The Brazilian sugar-ethanol sector

Brazil has a long history of sugarcane cultivation, with sugarcane traditionally cultivated in the country's North-East and South-East regions. In the 1970s, in response to the world oil crisis and rising prices of imported petroleum, Brazil instituted the National Alcohol Programme (ProÁlcool) to increase the use of sugarcane ethanol. While other countries lost interest as the cost of petroleum fell, Brazil invested heavily in infrastructure and research, driving down the cost of ethanol production. In the 2000s, national and international demand for biofuels rose, partly driven by increasing concerns about climate change and energy security. In Brazil, use of ethanol was aided by the introduction of flex-fuel vehicles in 2003, which enabled car engines to run on both ethanol and gasoline. By 2016, 73% of vehicles in Brazil were flex-fuel vehicles, and this rapid uptake was aided by ethanol becoming cost-competitive with gasoline [14.15]. Around this time, companies invested in plants designed to only produce ethanol, although many have since incorporated a sugar mill to provide greater production flexibility and to optimise profitability during periods of unfavourable ethanol pricing [16]. Of the country's 437 mills, the majority (67%) are ethanol distilleries attached to a sugar mill [14]. In the 2018/2019 harvest years, Brazil produced 33.1 billion litres of ethanol, making it the second largest producer of ethanol in the world (after the USA) [1,2].

In 2016, government support for ethanol was announced as part of Brazil's Nationally Determined Contribution to reduce national greenhouse gas (GHG) emissions under the 2015 Paris Agreement. Most recently, the RenovaBio programme, which was implemented in 2020, mandates fuel distributors to gradually increase the amount of biofuels they sell. The programme aims to double the use of ethanol by 2030 from 26 billion litres in 2018 [17,18]. However, a doubling in demand for ethanol will likely increase in the amount of land used to cultivate sugarcane with attendant environmental concerns [19].

Between 2000 and 2016, the area planted with sugarcane in Brazil more than doubled (see Figure 1) [3]. The total land area cultivated with sugarcane increased from 4.88 Mha to 10.25 Mha, with a concurrent increase in sugar, ethanol and bioelectricity production. Figure 1 shows the relative increase in sugarcane cultivation in Brazil and MS, revealing that the cultivation of sugarcane in MS outpaced that of Brazil's national level with a near ten-fold increase between 1988 and 2016. While the area cultivated with sugarcane in MS increased from 69,727 ha in 1988 to 658,282 ha in 2016 [3], this represents less than 2% of the state's territory. In MS, the rate of expansion accelerated from 2007 onwards, driven by the commercial introduction of flex fuel vehicles and rising land prices in São Paulo [20,21].

Figure 1. Relative expansion of sugarcane cultivation in Brazil and Mato Grosso do Sul, 1998-2016 (1988 = 100).



Source: Authors' own, based on [3]

Nearly half of Brazil's sugar mills are located in the state of São Paulo, which represents an agro-industrial cluster for the sugarcane industry. São Paulo is not only home to sugarcane cultivators and processors, but also to the research institutions and industrial associations that support the sector. This concentration and clustering of infrastructure and knowledge has promoted vertical and horizontal linkages, driving and diffusing innovation and enhancing access to markets and information [22]. While frontier states, such as MS, have ample land available for sugarcane expansion, there is no such cluster to support new sugar establishments. This may make it more challenging to realise the positive impacts associated with the sugarcane sector in São Paulo.

2.1. Understanding the impacts of sugarcane expansion

The rapid expansion of sugarcane has raised concerns about the negative environmental and social impacts of the sector, particularly deforestation in the Amazon and other areas of natural vegetation, such as the Cerrado biome. Deforestation, land use change and unsustainable agricultural practices have been shown to contribute to biodiversity loss, deterioration of water quality, air pollution, increased use of chemicals, and changes in nutrient cycles (e.g. [23]). To address many of these issues, the Brazilian Government and the sugarcane-ethanol sector have put in place policies and legislation [15,24]. For example, the approval of State Law 11, 241/2002 in São Paulo has seen the pre-harvesting burning of the sugarcane crop phased out; other states in the Centre-West region have adopted similar legislation. The shift from manual to mechanised harvesting has had social impacts, particularly reduced employment opportunities for lower skilled agricultural workers [25,26]. Another important tool was the adoption of the 2009 National Agro-Ecological Zoning for Sugarcane (ZAE Cana), which aims to guide the expansion of sugarcane into areas that are more favourable for cultivation [27]. The ZAE Cana provides a technical and scientific map based on environmental characteristics, such as climate, soil, vegetation and geomorphology for agricultural areas. Furthermore, in order to reduce impacts on food production, conversion of areas under pasture is preferred [28].

However, it is not just the environmental impacts of the sugarcane sector that have been criticized; indeed, the social impacts of sugarcane have also been subject to investigation. For example, the sector has long been criticised for its harsh conditions for manual sugarcane cutters [24,29]. As discussed, the introduction of State Law 11, 241/220 has seen manual harvesting largely eliminated in the Centre-West of Brazil. A consequence of this legislation has, however, been negative impacts on employment in the sector, with every mechanical harvester estimated to replace 100 jobs [29]. The working conditions on sugarcane estates have also been censured, with concerns about low remuneration, heavy workloads, lack of benefits and child labour [30,31]. National and international pressure have led the sector to improve working conditions, and it has been argued that conditions and wages are often better in the sugarcane sector than in other agricultural sectors in Brazil [15,24].

It is important to recognise that these high-level impacts of sugarcane will be experienced differently in different localities. Brazil is a highly unequal country and, according to the latest census [32], São Paulo has a Human Development Index (HDI) of 0.83, while the frontier states of MS, Goiás and Mato Grosso all have an HDI of 0.77. This will have implications for the capacity of regional and municipal governments to capture the potential benefits of sugarcane - a crop that has not traditionally been cultivated or processed in these states and where access to infrastructure, human capital and markets may be limited. The macro-economic characteristics of these states also vary; for instance, in MS nearly a quarter of GDP comes from agriculture, in contrast to São Paulo where it is 2% [33]. The impacts felt in each locality will therefore depend on regional dynamics and the characteristics of different localities [4].

There are few studies that examine how the socio-economic impacts of sugarcane vary across different Brazilian states. Machado et al. [5], for example, examined the socio-economic impacts of sugarcane cultivation in the states of São Paulo, Goiás and Alagoas. The authors used eight indicators to identify linkages between sugarcane activities and socio-economic impacts between 1970 and 2010. They found that municipalities in all three states with sugarcane activities presented better socio-economic indicators than those without, although only those municipalities in São Paulo presented significant differences. This analysis does not, however, provide an analysis by municipality nor does it examine the impacts on health. Brinkman et al. [4] uses an input-output model to examine socio-economic impacts of sugarcane on a micro-regional level in São Paulo and Goías. These authors also find differences between the microregions in terms of impacts on GDP and employment depending on economic structure, although the overall impact is largely positive. Again, however, this study did not analyse municipal-level impacts and, as a modelling study, examines future trends rather than analysing actual outcomes.

Several studies have examined the socio-economic impacts of the sugarcane sector at the municipal level, although most of these focus on the state of São Paulo. Chagas et al. [10] examined the impacts of sugarcane cultivation on municipal revenues in São Paulo and found that cane-growing municipalities had better fiscal performance than other agricultural municipalities. Martinelli et al. [23] found evidence that municipalities in São Paulo specialising in sugarcane had higher rates of social and economic development, due both to the generation of employment and better infrastructure. With a focus on municipalities in MS, Assunção et al. [13] applied panel data analysis and found that three years after a mill started operating, municipal GDP grew from 28% to 30%, and the population increased by 10% to 12%. The number of labour contracts for skilled workers also increased. However, it was unclear whether the shift to a more educated labour force was due to inward migration or whether the establishment of a mill positively impacted education at the local level. Similar questions pertain to who is able to capture value from cultivation of sugarcane: for instance, in Brazil in 2011/12, sugar mills cultivated 64% of the sugarcane that they processed, with the remaining 36% cultivated by independent farmers located nearby. Conversely, in the same year in MS, the sugarcane cultivated by the mills accounted for 73.4% [28]. This raises important questions about who benefits from the establishment of the sugar sector, and whether those benefits are realised locally.

2.2 Agriculture and land use in Mato Grosso do Sul

MS is a state located in the Centre-West region of Brazil. The state borders Paraguay and Bolivia and the Brazilian states of Paraná, São Paulo, Goiás and Mato Grosso. It has a land area of 357,145 km², making MS the sixth largest state in Brazil (out of 27). Administratively, MS is divided into 79 municipalities. Despite its large land area, MS is one of the least densely populated states in Brazil. According to the 2010 Census [32], the population was 2.5 million, of which 14% lived in rural areas and 86% lived in urban areas. In terms of economic activities, agriculture represents an important share of the state's GDP, particularly in comparison to other Brazilian states. In 2015, agriculture contributed 22% of its total value, making MS the Brazilian state with the second largest share of agriculture in GDP after Mato Grosso. In terms of other economic activities, industry represented 27% while services accounted for remaining 51% [33].

Land use in most municipalities in MS is dominated by pasture and cattle ranching. Of the land used for agricultural activities in 2015, 52% was dedicated to pasture, 3% sugarcane plantations, and 19% to other crops (including maize and soy) [33,34]. MS has undergone considerable land use change in recent decades, with areas devoted to cattle ranching switching to more profitable agricultural commodities, including soy and sugarcane. The expansion of agriculture in MS has placed ecosystems, such as the Cerrado, under threat [35] highlighting the importance of the ZAE Cana in determining where sugarcane cultivation can occur. Despite this rapid land use change, the ZAE Cana reveals that MS has significant potential for environmentally sustainable expansion of sugarcane, with up to 5.4 Mha considered apt [27].

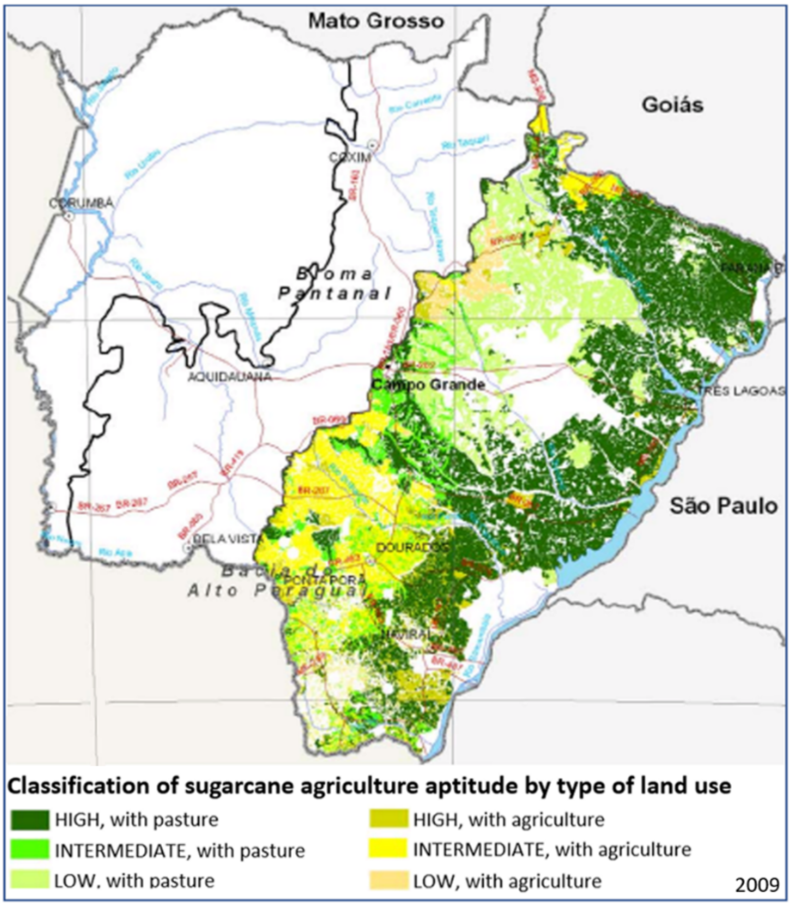
3. Materials and methods

To investigate the relationship between the presence or absence of sugarcane activities and municipal human development in MS, this research drew on publicly available data and adapted existing indices of human development. The methodology comprises five parts: i) identification of municipalities in MS considered apt for sugarcane using the ZAE Cana; ii) identification of land use i.e. whether land is used for pasture or crops; iii) identification of sugar mills operating in MS; iv) development of indicators to assess municipal human development; and, v) assessment of the relationship between human development to the presence or absence of sugarcane activities.

3.1. Identification of municipalities in MS with aptitude for sugarcane

ZAE Cana forbids sugarcane cultivation in 92.5% of Brazil's territory and identifies 64 Mha that comply with the conditions set out by Embrapa [15]. Around 15% of land area in MS is classified as suitable for sugarcane expansion, with 57 out of the 79 municipalities in MS considered apt for sugarcane cultivation. All 57 municipalities are located in eastern MS and are thus close to the states of São Paulo and Goias and the main domestic fuel markets. Land area that is considered apt for sugarcane in MS according to the ZAE is shown in Figure 2.

Figure 2. Agroecological Zoning of sugarcane, Mato Gross do Sul



Source: adapted from [27].

The review of the ZAE Cana led to the exclusion from further analysis of those municipalities that were not considered apt for sugarcane cultivation. The reasons are given as follows: (i) not apt municipalities have characteristics (e.g. protected areas) that could also discourage the establishment of other economic activities, so their consideration in the analysis could distort the comparison between indicators; (ii) apt areas are concentrated in eastern MS, therefore, regional heterogeneity among the east and west of MS could reveal socio-economic differences that are related to other factors than the presence or absence of sugarcane; and (iii) policies for establishment of the sugarcane sector would be flawed for municipalities considered not apt.

3.2. Assessment of Land Use in Mato Grosso do Sul

To better understand how the land in municipalities of MS is used, data regarding pasture areas and areas dedicated for the harvesting of temporary and permanent crops were collected from the Brazilian Institute of Geography and Statistics (IBGE, in Portuguese). For simplicity, the authors will use the term ‘planted area’ when referring to area dedicated for harvesting. It is important to note that some crops, such as maize, have short growing periods and an area cultivated with those crops may be harvested more than once per year. While this may overestimate the cultivated land area, an analysis of crop rotation and crop dynamics was considered beyond the scope of this paper.

To compare the amounts of pasture and agricultural areas in each municipality, data on ‘total pasture area’ and ‘total planted area’ from 2015 were used [33,34]. To analyse the shares of different crops cultivated, data from 2015 regarding planted areas of sugarcane and ‘other crops’ including maize, soybeans and other permanent (e.g. orange and coffee) and temporary (e.g. wheat and beans) crops were gathered [33]. This enabled an assessment of predominant agricultural activity and the share of sugarcane planted areas in the agriculture sector for each studied municipality in MS.

3.3. Identification of sugar mills

A list and the location of sugar mills operating in MS was compiled using different online sources, including UDOP (the National Union of Bioenergy), UNICA (the Brazilian Sugarcane Industry Association), BioSul (the Association of Bioenergy Producers in MS) and ANEEL (the Brazilian Electricity Regulatory Agency). It was also important to ascertain the year each mill was established, which was found on the websites of individual mills and/or the ANEEL database.

3.4. Assessment of Municipal Human Development

To assess the relative human development of municipalities in MS, this analysis built on two existing indices: the UN HDI [36], and the Paulista Social Responsibility Index (IPRS, in Portuguese) [37]. The HDI is a composite index of three dimensions of human development: health, education and wealth. The HDI enables comparisons within and across nations; however, because it comprises a limited number of indicators it provides only a partial view of a country or region’s performance. As a globally applicable composite index, the HDI is designed to enable inter-country comparison and, almost by definition, does not accurately capture the local realities of human development. In recognition of this, the IPRS was developed by the Seade Foundation to assess municipal development in São Paulo state [37]. The IPRS uses the three dimensions of the HDI but adopts additional indicators to reflect issues relevant to human development in São Paulo and enable longitudinal assessment. The IPRS only applies to the state of São Paulo and there is no human development index for MS. An important step was therefore to develop an appropriate measure of human development that was relevant to the state of MS.

The MS assessment method builds on the HDI and IPRS. As per the HDI, the MS assessment analyses the three dimensions of human development (i.e. health, education and wealth) and, wherever possible, uses the same indicators as the IPRS. However, differences in data availability meant that this was not always possible. Table 1 compares the variables used in the IPRS and MS assessment. For this paper, data were collected for 2007 and 2015 to enable analysis over time. These years were selected for two reasons: data availability and wider trends in biofuel markets. 2007 was chosen as the base year, since this was when the area planted with sugarcane in MS began to increase rapidly (see Figure 1), while 2015 was chosen as it was the most recent year for which all data was available.

Table 1. Indicators used in the IPRS and MS Assessment.

Dimension of Human Development		IPRS	MS Assessment
Wealth	**W1**	Average annual electricity consumption per residence	Average annual electricity consumption per residence
	W2	Average annual electricity consumption per consumer in the agriculture, service and commerce sectors	Average annual electricity consumption per consumer in rural areas and public services, industry and commerce sectors
	W3	Municipal added fiscal value per capita	GDP per capita
	W4	Average remuneration of active formal employees	Average remuneration of active formal employees
Health	**H1**	1 - Perinatal mortality rate	1 - Perinatal mortality rate
	H2	1 - Child mortality rate	1 - Child mortality rate.
	H3	1 - Mortality rate of people aged 15 to 39 years old	1 - Mortality rate of people aged 15 to 39 years old
	H4	1 - Mortality rate for people aged 60 to 69 years old	1 - Mortality rate for people aged 60 to 69 years old
Education	**E1**	School attendance of children aged 4 to 5 years old	School attendance of children aged 4 to 5 years old
	E2	Proportion of 5th grade students with adequate performance in mathematics and Portuguese national tests	Average score of 5th grade students in mathematics and Portuguese national tests
	E3	Proportion of 9th grade students with adequate performance in mathematics and Portuguese national tests	Average score of 9th grade students in mathematics and Portuguese national tests
	E4	1 - Age-grade distortion rate of high school students	1 - Age-grade distortion rate of high school students

Source: authors' own and [37]

The calculation and data sources for each indicator are detailed in next subsections. The set of municipalities is denoted by M. For simplicity, the variables that correspond to the wealth dimension are denoted by W_1, W_2, W_3 and W_4; those for the health dimension are H_1, H_2, H_3 and H_4; and those for education dimension are E_1, E_2, E_3 and E_4.

3.4.1 Wealth

Indicator W_1 is the average electricity consumption per residence. The dataset for this indicator was obtained from [38]. Its value for a municipality i is calculated according to equation (1).

$$W_{1,i} = \frac{ElRes_i}{Res_i}, \ \ i \in M \qquad (1)$$

where $ElRes_i$ is the total residential electricity consumption in municipality i; and Res_i is the total number of residences that consume electricity in municipality i.

Indicator W_2 is the average annual electricity consumption per consumer in rural areas and public services, industry and commerce sectors. The dataset for this indicator was collected from [38]. Its value for a municipality i is obtained according to equation (2).

$$W_{2,i} = \frac{ElSec_i}{Sec_i}, \ i \in M \quad (2)$$

where $ElSec_i$ is the total electricity consumption of rural areas and public service, industry and commerce sectors in municipality i; and Sec_i is the total number of establishments within these categories that consume electricity in municipality i.

Indicator W_3 is municipal GDP per capita, which is calculated based on municipal GDP (IBGE, 2017) and population [39]. Thus, $W_{3,i}$ denotes the GDP per capita of municipality i.

The last indicator of the wealth dimension is W_4, which is the average remuneration of active employees. The remuneration dataset was obtained from the Annual Relation of Social Information (RAIS) provided by the Brazilian Labour Ministry [40]. Its value for a municipality i is given by equation (3).

$$W_{4,i} = \overline{rem}_i, \quad i \in M \quad (3)$$

where $\overline{rem}_i$ is the average nominal remuneration of formally active employees in municipality i.

3.4.2. Health

Indicator H_1 is based on the perinatal mortality rate, which is defined by the ratio between the sum of total deaths of children from 0 to 6 days old and stillbirths, and the sum of total births and stillbirths in the same period, multiplied by 1,000. The data were collected from the Brazilian Health Ministry information system [38]. The value of H_1 for a municipality i is calculated according to equation (4).

$$H_{1,i} = 1 - 1{,}000\left(\frac{dea_i^{\frac{0}{6}} + stb_i}{birt_i + stb_i}\right), \quad i \in M \quad (4)$$

where $dea_i^{0/6}$ is the number of deaths of children from 0 to 6 days old in municipality i, $birt_i$ is the number of births in municipality i, and stb_i is the number of stillbirths in municipality i.

Indicator H_2 is calculated based on the child mortality rate, which is defined by the ratio of the sum of the number of deaths of children younger than 1 year old, and the total births in the same period, multiplied by 1,000. The data were collected from [39]. The value of H_2 for a municipality i is given by equation (5).

$$H_{2,i} = 1 - 1{,}000\left(\frac{dea_i^{\frac{0}{365}} + stb_i}{birt_i + stb_i}\right), \quad i \in M \quad (5)$$

where $dea_i^{0/365}$ is the number of deaths of children from 0 to 365 days old in municipality i; and $birt_i$ and stb_i being births and stillbirths, as explained for H_1.

Indicator H_3 measures the mortality rate of people aged between 15 and 39 years old. The data were collected from [39]. The value of H_3 for municipality i is expressed by equation (6).

$$H_{3,i} = 1 - 1{,}000\left(\frac{dea_i^{\frac{15}{39}}}{pop_i^{\frac{15}{39}}}\right), \quad i \in M \quad (6)$$

where $dea_i^{15/39}$ is the number of deaths of people from 15 to 39 years old in municipality i, and $pop_i^{15/39}$ is the population from 15 to 39 years old in municipality i.

Indicator H_4 is the mortality rate of people aged between 60 and 69 years. The data were collected from [39]. The value for municipality i is expressed by equation (7).

$$H_{4,i} = 1 - 1{,}000\left(\frac{dea_i^{\frac{60}{69}}}{pop_i^{\frac{60}{69}}}\right) , \qquad i \in M \tag{7}$$

where $dea_i^{60/69}$ is the number of deaths of people aged 60 to 69 years in municipality i, and $pop_i^{60/69}$ is the population aged 60 to 69 years in municipality i.

3.4.3. Education

Indicator E_1 assesses the school attendance of 4 to 5-year olds. These data were collected from [39,31]. The value of E_1 for a municipality i is expressed by equation (8).

$$E_{1,i} = \frac{enr_i^{4/5}}{pop_i^{4/5}} \quad , \quad i \in M \tag{8}$$

where $enr_i^{4/5}$ is the number of enrolments of 4 to 5-year olds in municipality i, and $pop_i^{4/5}$ is the total population of 4 to 5-year olds in municipality i.

Indicators E_2 and E_3 are respectively the average proficiency of 5th and 9th grade public school students in Mathematics and Portuguese in the Brazilian test [41]. The values for both are given by equations (9) and (10).

$$E_{2,i} = \frac{Ma_i^{5th} + Po_i^{5th}}{2} \quad , \quad i \in M \tag{9}$$

$$E_{3,i} = \frac{Ma_i^{9th} + Po_i^{9th}}{2} \quad , \quad i \in M \tag{10}$$

where Ma_i^{5th}, Ma_i^{9th}, Po_i^{5th} and Po_i^{9th} are respectively the average proficiency in Mathematics of 5th and 9th public school students in municipality i, and average proficiency in Portuguese of 5th and 9th public school students in municipality i.

Indicator E_4 is based on the age-grade distortion rate in high school [41], which is defined as the proportion of high school students that would be delayed by at least two years by the end of the school year. Its calculation for municipality i is expressed by equation (11).

$$E_{4,i} = 1 - \left(\frac{st_i + nd_i + rd_i}{hs_i}\right) \; , \; i \in M \tag{11}$$

with st_i, nd_i and rd_i are respectively the number of enrolled students in municipality i that by the end of the school year would be delayed by at least two years to attend the first, second and third grades of high school; and hs_i is the number of enrolments in high school in municipality i.

3.4.4. Paired t-test for variation in socio-economic indicators

To identify whether there was a significant relative improvement in human development between 2007 to 2015, each indicator was relativized according to equation (12).

$$relative\ value_i^{k,y} = \frac{value_i^{k,y} - \left(value_i^{k,y}\right)}{\max_i\left(value_i^{k,y}\right) - \min_i\left(value_i^{k,y}\right)} \tag{12}$$

where $k \in \{W1, W2, \ldots, E4\}$, $i \in set\ of\ municipalities$, and $y \in \{2007, 2015\}$ and analysed separately.

A paired unilateral t-test was performed to test for mean difference between 2015 and 2007 considering a 10% significance level, which corresponds the null hypothesis:

$$H0\colon \mu(relative\ value^{k,2015}) - \mu(relative\ value^{k,2007}) = 0$$

$\mu(.)$ denotes the mean parameter value. The alternative hypothesis is adopted in function of sign of observed mean difference of the samples. If the observed mean difference of the samples was positive, a right tail t-test, that is:

$$H1_{right\ tail}\colon \mu\left(relative\ value^{k,2015}\right) - \mu\left(relative\ value^{k,2007}\right) > 0$$

Otherwise, the left tail t-test was adopted if the observed mean difference of the sample was negative, that is:

$$H1_{left\ tail}\colon \mu\left(relative\ value^{k,2015}\right) - \mu\left(relative\ value^{k,2007}\right) < 0$$

This paired t-test was applied separately for four (sub)groups of municipalities: (i) all 57 municipalities; (ii) municipalities without a mill (n=37); (iii) all municipalities with a mill (n=20); (iv) municipalities that established a mill between 2007 and 2015 (n = 12). The results of the t-test are presented in subsection 4.3.

3.5. Clustering of municipalities in Mato Grosso do Sul

To provide a single index for each dimension of human development, the IPRS applies factor analysis to collapse the four indicators into one [37]. A disadvantage of factor analysis is that large amounts of information can be lost. For example, in the IPRS the wealth factor has a loss of 39%, health 48% and education 49% [37]. For the MS assessment, factor analysis revealed unacceptably high levels of information loss (48% for wealth, 44% for health and 60% for education). To overcome this limitation, this study used a K-means clustering methodology [42]. This enabled identification of two groups of municipalities with similar performance regarding the twelve indicators presented in Table 1 - those performing ‘better’ and those performing ‘worse’ on human development. This was undertaken for two years - 2007 and 2015 - as explained in 3.4.

The K-means clustering algorithm was applied, and Euclidean distance was chosen to measure the similarity between municipalities and groups. K-means was chosen as the clustering algorithm because it enables analysis for a pre-determined number of cluster centres and then the most suitable value for K can be adopted; in this study K = 2. To improve the algorithm capacity of splitting the municipalities into ‘better’ and ‘worse’ performing groups, the initial centroids were chosen as:

$$C_{worse} = (0, 0, 0, \dots, 0) \in \mathbb{R}^{12} \text{ and } C_{better} = (1, 1, 1, \dots, 1) \in \mathbb{R}^{12}.$$

Visual analysis on the boxplots of the variables were the criteria to check if the algorithm provided a good separation of the groups (i.e. ‘better’ and ‘worse’ performing groups).

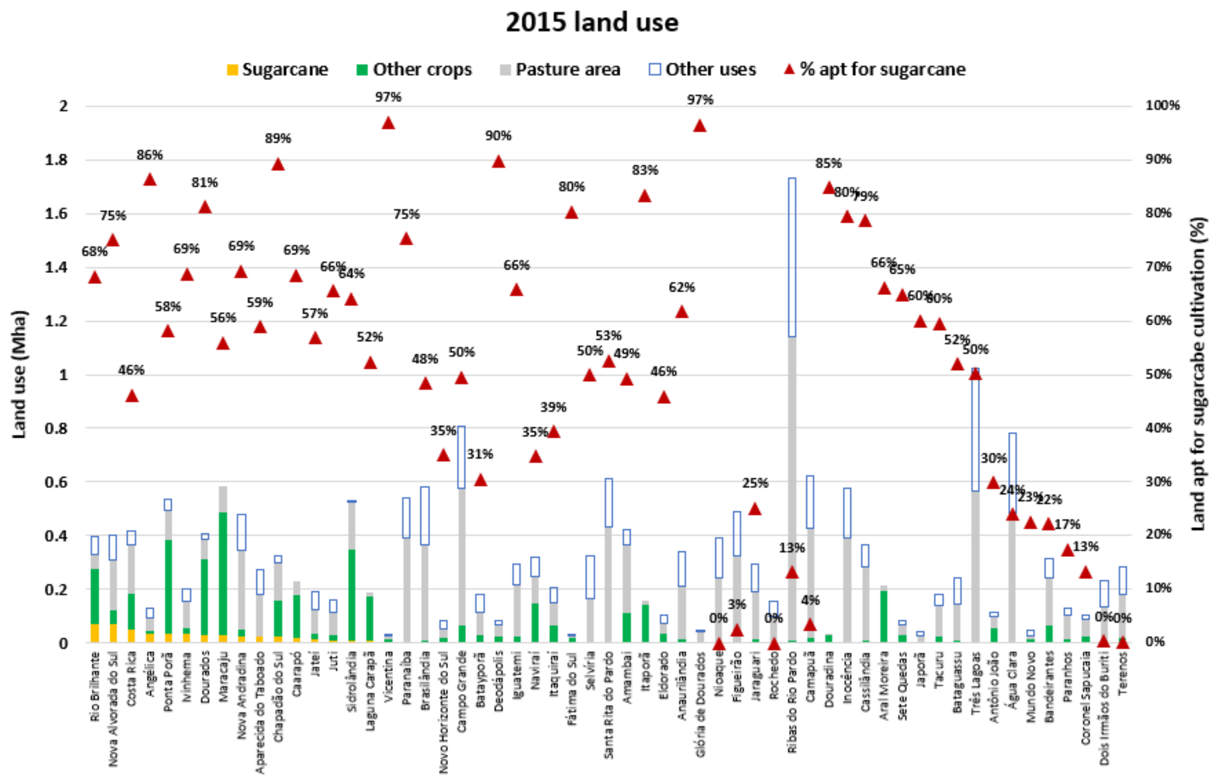
4. Results

4.1. Land use in Mato Grosso do Sul

Analysis of data from the ZAE Cana shows that there is a total of 8.7 Mha of land in MS characterised as having a ‘high’ to ‘medium’ aptitude for sugarcane. It reveals that 57 out of 79 municipalities have land that is apt for the cultivation of sugarcane; however, the percentage of suitable land varies from less than 0.05% (Nioaque) to 97% (Vicentina) of total land area. Those municipalities located close to protected areas, areas of natural vegetation, including the Pantanal and Cerrado, and important watercourses have lower proportions of land considered apt for the cultivation of sugarcane.

Figure 3 shows three sets of data: municipal land area, agricultural land use for each municipality, and the percentage of total land area in each municipality that is considered apt for sugarcane. It reveals the enormous differences in the size of the municipalities: the largest, Ribas do Rio Pardo, has more than 60 times the land area of the smallest municipality, Douradina (1.73 Mha and 28,079 ha respectively).

Figure 3. Land area (Mha), agricultural land use (Mha) and land apt for sugarcane (%) by municipality, Mato Grosso do Sul, 2015.



Source: authors' own, using data from [33,34].

In 2015, pasture dominated land used for agriculture in MS. The primary agricultural crops were soy and maize, which were cultivated far more extensively than sugarcane. Sugarcane accounted for 0.52 Mha, with 'other crops' (dominated by soy and maize) accounted for 3.6 Mha.

Only one municipality was cultivating more land with sugarcane than was considered apt; Nioaque was cultivating 200ha (out of 27ha considered apt). For all other municipalities – where much higher proportions of land were considered apt – none had reached their potential in terms of land considered apt for the cultivation of sugarcane.

Of the land in MS considered apt for sugarcane cultivation, only 6% had been used for this purpose in 2015, this indicates that there was considerable land available for the expansion of sugarcane. Since this expansion would only occur on land considered ecologically suitable for sugarcane, it should not – in theory – have negative environmental impacts on e.g. water, soil or natural vegetation. However, the conversion of land formerly dedicated to pasture or less profitable agricultural commodities is likely to lead to indirect land use change through the displacement of these activities.

4.2. Identification of sugar mills in Mato Grosso do Sul

There are 25 sugar mills operating in MS (out of more than 400 in Brazil) and a further three are planned (Figure 4). The majority produce bioelectricity in addition to sugar and ethanol [43,44]. Four mills were established in the 1980s, two in the 1990s and two in the early-2000s, but the majority (17) were established post-2006 following the introduction of flex-fuel vehicles. One mill is located in the municipality of Sonora, which is not considered apt for sugarcane; however, this mill began operating in 1984, prior to the ZAE Cana and is therefore excluded from further analysis. Of the 57 municipalities considered apt for sugarcane, 20 had sugar mills. Three municipalities had more than one sugar mill: Maracajú (2); Nova Alvorada do Sul (2); and Rio Brilhante (3).

Figure 4. Map of Mato Grosso do Sul with the location of sugar mills, 2019.

4.3. Assessment of Human Development Indicators in Mato Grosso do Sul

Results of the paired t-test are presented in Table 2. P-values < 0.05 (i.e. 5% significance test) for the right tail t-test are marked in orange, while for the left tail t-test are marked in blue. Although some significant differences were obtained, there is no clear relationship between the presence of a mill and relative municipal socio-economic development between 2007 and 2015.

Table 2. Paired mean difference test between values in 2007 and 2015

Group of municipalities	Statistics	Wealth Indicators				Health Indicators				Education Indicators				Number of municipalities
		W1	W2	W3	W4	H1	H2	H3	H4	E1	E2	E3	E4	
All	t_obs	2.065	1.133	0.751	0.633	1.304	0.177	2.006	2.195	-2.403	-1.807	-0.148	0.934	57
	p-value	0.022	0.131	0.228	0.265	0.099	0.430	0.025	0.016	0.010	0.038	0.442	0.177	
Without a mill	t_obs	1.407	0.730	-0.111	-1.149	0.294	-0.478	1.938	0.772	-2.361	-1.808	0.478	0.164	37
	p-value	0.084	0.235	0.456	0.129	0.385	0.318	0.030	0.223	0.012	0.039	0.318	0.435	
With a mill	t_obs	1.873	1.078	1.074	3.001	2.249	1.289	0.819	2.820	-0.967	-0.661	-1.020	1.544	20
	p-value	0.038	0.147	0.148	0.004	0.018	0.107	0.211	0.005	0.173	0.258	0.160	0.070	
Mill established between 2007 and 2015	t_obs	2.135	0.888	1.696	4.127	2.054	1.536	0.249	1.014	-0.135	0.813	-0.161	0.358	12
	p-value	0.028	0.197	0.059	0.001	0.032	0.076	0.404	0.166	0.448	0.217	0.437	0.363	

4.4. Cluster analysis

The K-means clustering revealed two groups of municipalities: Group 1 comprises those municipalities performing relatively better, while Group 2 were those performing relatively worse. Figure 5 presents the box-plots of the relativized indices for 2007 and 2015.

Figure 5. Box-plots of the relativized indices – Group 1 x Group 2 – Years 2007-2015

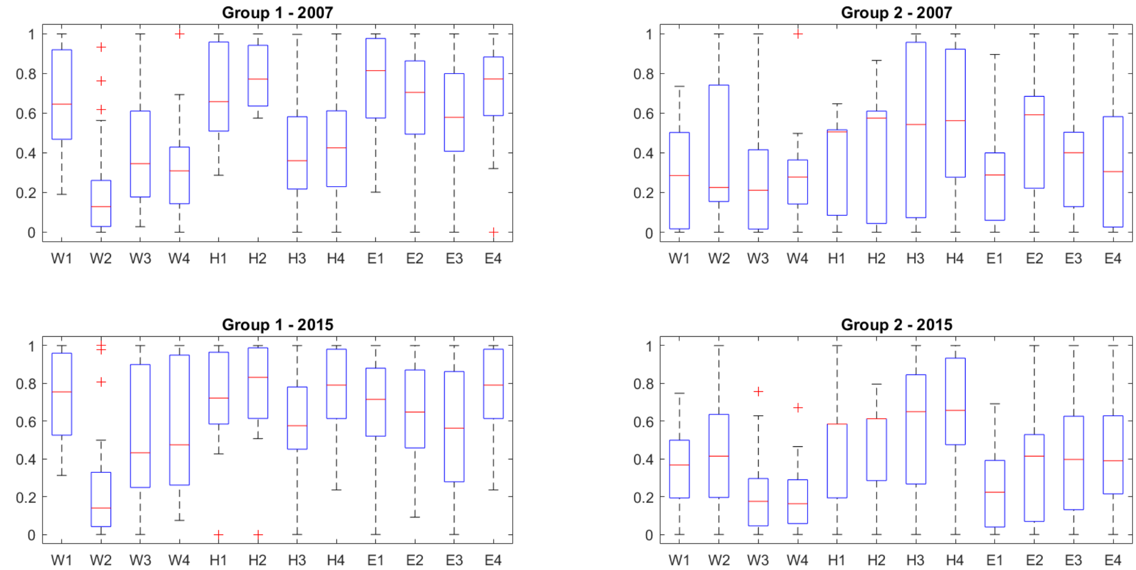


Figure 6 shows the location of municipalities in Groups 1 and 2 for 2007 and 2015. Table 4 presents the frequency of the municipalities between groups and year and number of sugarcane mills in each group.

Figure 6. Locations of municipalities in Group 1 (better) and Group 2 (worse), 2007 (left) and 2015 (right).

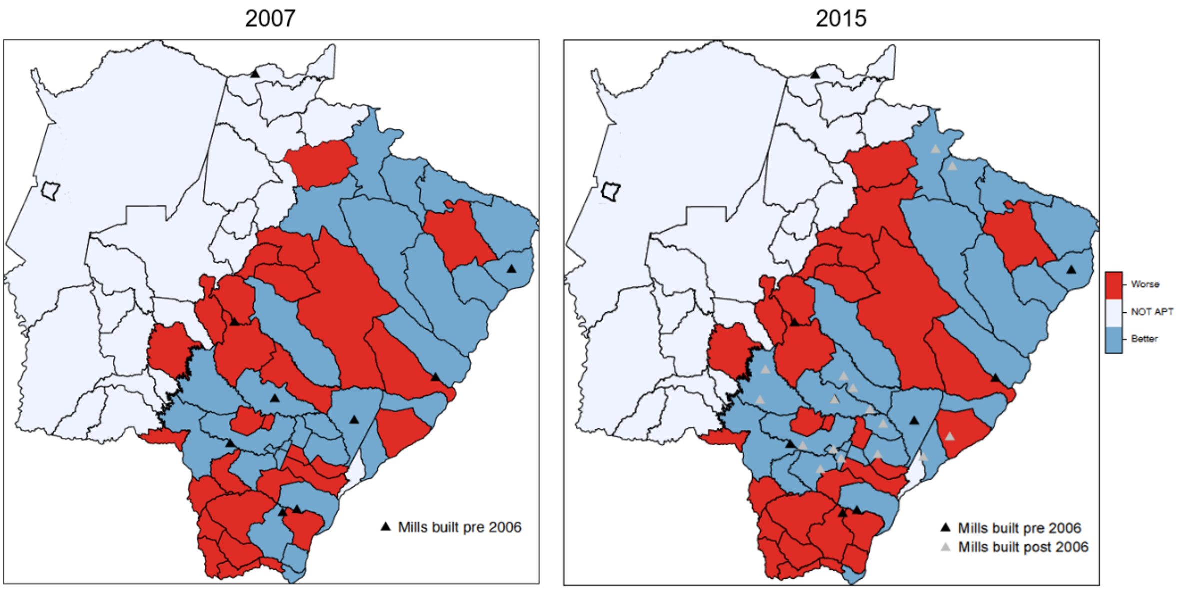


Table 3. Frequency of municipalities in each Group, per year

	Group 1 – 2015	Group 2 – 2015
Group 1 – 2007	24 municipalities (16 with mills – 6 built before 2007 and 10 between 2007 and 2015)	4 municipalities (1 with mill built before 2007)
Group 2 – 2007	3 municipalities (1 mill built in 2007)	26 municipalities (2 with mills – 1 built before 2007 and 1 between 2007 and 2015)

The results show that most municipalities with a mill performed relatively better in 2007 and continued to do so in 2015. This provides some evidence of a positive relationship between socio-economic development and the presence of a mill. However, most of those municipalities that had mills established between 2007 and 2015 were already in Group 1 (better), highlighting that siting decisions by sugar companies depend on more than just availability of land apt for sugarcane.

Of the three municipalities with mills that belonged to Group 2 (worse), two showed no relative change in human development between 2007 and 2015 and one progressed to Group 1. One municipality with a mill belonged to Group 1 in 2007 and to Group 2 in 2015.

Table 4 shows the municipality classification in 2007 and 2015 and, where a municipality had a mill, the year the mill was established.

Table 4. Municipalities Classification

Municipality	Group		Year mill established	Municipality	Group		Year mill established
	2007	2015			2007	2015	
Água Clara	1	1	-	Ribas do Rio Pardo	2	2	-
Amambai	2	2	-	Rochedo	2	2	-
Antônio João	2	2	-	Santa Rita do Pardo	2	2	-
Aral Moreira	2	2	-	Selvíria	1	1	-
Bandeirantes	2	2	-	Sete Quedas	2	2	-
Bataguassu	1	1	-	Tacuru	2	2	-
Camapuã	1	2	-	Terenos	2	2	-
Campo Grande	1	1	-	Três Lagoas	1	1	-
Cassilândia	1	1	-	Aparecida do Taboado	1	1	1981
Coronel Sapucaia	2	2	-	Nova Andradina	1	1	1981
Deodápolis	1	2	-	Naviraí	1	1	1984
Dois Irmãos do Buriti	2	2	-	Brasilândia	1	1	1991
Douradina	2	2	-	Sidrolândia	2	2	1996
Eldorado	1	2	-	Rio Brilhante	1	1	2001
Figueirão	2	2	-	Iguatemi	1	2	2002
Glória de Dourados	2	1	-	Ponta Porã	1	1	2006
Inocência	2	2	-	Batayporã	1	1	2007

Itaporã	2	2	-	Fátima do Sul	1	1	2007
Itaquiraí	2	2	-	Nova Alvorada do Sul	2	1	2007
Japorã	2	2	-	Anaurilândia	2	2	2009
Jaraguari	2	2	-	Angélica	1	1	2009
Jateí	2	2	-	Caarapó	1	1	2009
Juti	2	2	-	Chapadão do Sul	1	1	2009
Laguna Carapã	2	1	-	Dourados	1	1	2009
Mundo Novo	1	1	-	Maracaju	1	1	2009
Nioaque	2	2	-	Vicentina	1	1	2009
Novo Horizonte do Sul	2	2	-	Costa Rica	1	1	2011
Paranaíba	1	1	-	Ivinhema	1	1	2014
Paranhos	2	2	-				

5. Discussion

With increased demand for sugarcane products and saturation of cultivation areas in São Paulo, where activities have traditionally been located, investors have expanded into new regions to locate their activities. The state of MS is one such frontier region and has experienced a rapid increase in both plantation area and the number of sugar mills. Nevertheless, the land use assessment undertaken for this paper, revealed that in 2015 most land considered ‘apt’ for sugarcane cultivation was not being used for this purpose. Rather, pasture continued to dominate the state’s agricultural sector, suggesting that there is still considerable potential for new sugarcane-related investments in MS. However, while the environmental conditions of both São Paulo and MS are favorable for sugarcane cultivation, they exhibit considerable differences in terms of their economies and levels of human development. Indeed, in 2017, two mills in MS closed due to challenging economic conditions [45,46]. This raises important questions about the extent to which MS, as a state at the frontier of sugarcane expansion, is able to realise the socio-economic benefits evidenced in Sao Paulo. This paper has taken an important first step towards addressing this knowledge gap by examining whether there is a relationship between human development and sugarcane activities.

The paired t-test was used to test for a relationship between the presence or absence of a mill and changes between 2007 and 2015 in the relative mean values of each indicator of human development. Four groups of municipalities were considered: (i) all 57 municipalities; (ii) municipalities without a mill (n=37); (iii) all municipalities with a mill (n=20); (iv) municipalities that established a mill between 2007 and 2015 (n = 12). The aim was to assess relative improvements in the human development indicators for those municipalities where a mill was established between 2007 and 2015 (i.e. group iv) compared to other groups (i.e. groups i-iii). The results showed that there was no relationship between the establishment of a mill and relative change in the human development indicators. In other words, those municipalities that had performed relatively better in 2007 continued to do so in 2015 and vice versa. While these results are statistically significant, no conclusions can be made about causality[1] and there is a need for research that elucidates the mechanisms by which sugarcane cultivation and processing improves local human development.

After grouping the municipalities according to the establishment of mills and assessing each group regarding their relative changes in human development indicators (paired t-test), the opposite rationale was done: the municipalities were grouped according to their socio-economic similarities and the groups were then compared according to when a mill was established. A clustering algorithm (K-means) enabled the municipalities to be grouped for the years 2007 and 2015 and, by assessing the distribution of the values of each indicator in each group, the municipalities were grouped into Group 1 ('better') and Group 2 ('worse'). The establishment of mills in each group was then analysed (Table 3). Results indicated that for both years, the group of more developed municipalities are where investors chose to locate their refineries and that these municipalities continue to perform relatively better after the mill is established. This indicates that investors demonstrate a preference for establishing sugar mills in more developed municipalities, and that the establishment of a mill does not have a negative impact on human development. This finding highlights the importance of siting decisions beyond the availability of land considered apt for sugarcane.

The sugar sector and other agro-industries are undoubtedly important for rural economies in MS and Brazil more generally – providing jobs and a low carbon source of energy, attracting investment and supporting the development of infrastructure. However, a key challenge for frontier regions is not only to attract investment, but also for state and municipal governments to capture and retain value locally. In MS, Assunção et al. [13] find positive impacts on employment where a mill is present; however, it is not clear who fills the jobs that are created. As shown in this analysis, levels of education across MS vary greatly and without investment in education, skills and training, many jobs may go to skilled migrants rather than being filled locally. As many of the more recently established mills are owned by large (multi)national companies, such as Raizen, Dreyfus and Odebrecht, there may also be a preference for transferring existing employees (e.g. from São Paulo), rather than employing local people. Local news provide evidence to support this theory, with claims of mills failing to provide job opportunities for workers from the municipalities in which they are located [47]. One mill, Aurora in Anaurilandia, had received 300 ha from the municipality in exchange for the creation of 800 direct and 2,500 indirect jobs within 10 years, but had only created 500 jobs by the time it closed in 2017 [46]. The increased importance of mechanisation has also reduced employment opportunities in the sugar sector, particularly for unskilled labour. This presents a challenge, particularly in rural areas characterised by low levels of education and may require mills to provide vocational training for local workers. Where jobs are created and who benefits is an important issue that warrants further investigation.

This raises the critical question of whether the expansion of sugarcane can be directed so that it delivers maximum socio-economic benefit and minimum environmental harm along sugarcane frontiers, such as MS. This research has demonstrated a positive relationship between human development and the presence of a mill; however, it also suggests that the sector has expanded

[1] Hypothetical example: If a municipality presents the best (worse) value for an indicator in 2007, then its relative value would be equal 1 (0). Supposing that the establishment of a mill between 2007 and 2015 improves (worsens) its indicator and that this municipality will also present the best (worst) indicator value in 2015. In this case the relative values of 2007 and 2015 will be both equal 1 (0) for this municipality and the impact caused by the establishment of the mill (change in the indicator value) would not be captured.

into more developed municipalities and has done little to address inequalities between municipalities in MS. This includes not only those municipalities with a mill, but also those that cultivate but do not process sugarcane.

6. Conclusions

This paper has developed a methodology for assessing the relationship between human development at the municipal level and the presence or absence of sugarcane in MS - a sugarcane frontier region. This research combined an assessment of land use with data on municipal human development for two years, 2007 and 2015, a period which captures rapid change in the sugar sector. The research found evidence of a relationship between the presence of a sugarcane mill and human development, and this finding supports other assessments that have found a positive relationship between sugarcane and socio-economic development (e.g. [10,13]. However, it also found that investors have a preference for municipalities with higher levels of human development. This suggests that it is not just aptitude for sugarcane that attracts investors to locate in a particular municipality, and further research is required to understand what drives siting decisions. This will be important not only to support the development of policies that attract investment, but to ensure that the benefits of these investments are felt locally, thus contributing to every dimension of human development.

RenovaBio promises to boost biofuel production in Brazil, in all likelihood driving further expansion of sugarcane into frontier states, such as MS. The ZAE Cana identifies 8.7 Mha of land in MS as ‘apt’ for sugarcane; even if a small amount of this land is converted to sugarcane, the potential direct and indirect impacts - on environment, society and economy - are significant. While much research has been focused on the environmental impacts of expansion, the impacts on human development are equally important. This raises important questions for energy and agricultural policy about how sugar can contribute to human development at the municipal level, where they could benefit more, and the extent to which local policy mechanisms can be (re)designed to encourage some practices and discourage others. Further research is urgently required to ensure that the expanding sugar sector contributes to human development in Brazil’s frontier states.

Acknowledgements

This work was financed in part by a NERC-FAPESP grant, NE/N018656/1, under the Brazil-UK partnership, and by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

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