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Interregional assessment of socio-economic effects of sugarcane ethanol production in Brazil

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A R T I C L E I N F O

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A B S T R A C T

Brazil is the largest producer of sugarcane ethanol worldwide (28 billion litres in 2013) and its production is expected to increase substantially in the coming years. As the sugarcane ethanol sector contributes significantly to the national economy, an expansion of production impacts GDP, employment and trade; these impacts are not equally distributed throughout the country, nor between income classes. These differences between regions and income classes are not well understood since previous studies on socio-economic impacts used high aggregation levels. The objective of this study is to compare the distribution of socioeconomic impacts of sugarcane ethanol production expansion in Brazil, including the interregional effects, across three microregions in the Centre South and different income classes. The spatial distribution of sugarcane for the supply of 54 billion litres of ethanol in 2030 was used as input for an interregional input-output model. Three scenarios for the quantity and location of sugarcane production are studied, based on measures to limit land use (i.e. second generation ethanol, higher agricultural yields). The results show that expansion of sugarcane ethanol production in Brazil in 2030 could increase the national GDP by 2.6 billion USD and employment by 53,000 fte. In general the microregional benefits of sugarcane expansion outweigh the downsides from displaced production of other crops and livestock. The microregions also benefit to varying extents from sugarcane ethanol expansion outside their borders. Additional employment is primarily generated in lower income classes. There are considerable differences in the impacts across the regions, these are related to the structure of the local economy and the scenario and not only dependent on the local potential for sugarcane expansion. Socio-economic impacts of biofuel production should thus be studied on lower aggregation levels to include these differences in benefits across regions and income classes.

1. Introduction

Global energy security and climate change mitigation are important drivers for a shift towards alternative, renewable energy sources [1]. Bioenergy is currently the most important renewable energy source [2] and it is expected to play a substantial role in the diversification of the energy mix in the future [3]. A key role is reserved for biofuels that replace liquid fossil fuels in the transport sector in the short to mid-term [4]. Brazil has become one of the most prominent producers of renewable transport fuel in the world since the launch of the Pró-Álcool policy in 1975, in which the Brazilian government promoted and supported the development of the sugarcane ethanol sector [5]. Today, the country is the second largest producer and an important exporter of ethanol globally [6,7]. Production in the harvest year 2013/14 equalled just over 28 billion litres [8], and is expected to grow in the coming years [9,10].

In addition to its renewable character, the use of ethanol instead of fossil fuels is associated with environmental benefits, such as climate change mitigation and reduction in lead and sulphur emissions [11]. However, with increasing production, the sugarcane ethanol sector has

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come under greater scrutiny with regards to its sustainability. Despite only 1.2% of the total land surface in Brazil being occupied with sugarcane [12], concerns have been expressed about land use change and associated deforestation, risks of losing biodiversity and negative impacts on water quality and availability [11,13–18]. These problems could be exacerbated by the expected increases in demand for and production of ethanol.

It is not only environmental sustainability that is important for sustainable development, as socio-economic sustainability is also an important aspect [19,20]. This is also reflected in the United Nations Sustainable Development Goals (SDGs) that include goals such as poverty reduction, decent work, economic growth and improving rural livelihoods [21]. A literature review shows that biofuel feedstock production can also contribute to socio-economic development in rural regions [10,22–26]. These contributions to rural development can be made through investments in capital goods and additional demand for labour in the conversion plants and on the field. Furthermore, reduced dependency on (fossil) fuel imports, together with the export potential of biofuels, can strengthen national and regional economies [27,28]. Indirect contributions result from increased production in the sectors of the economy that supply inputs to the biofuel sector. Furthermore, increased employment can add household income and purchasing power which generates additional spending in the economy (also called induced impacts) [29]. With an increased role for biofuels in the future energy supply, positive effects are expected on the key socio-economic indicators GDP, employment and trade [17]. However, an expansion of biofuel production and the related impacts will not be evenly spread throughout the country [30]. Rather, the direction and the size of impacts in each region depend on specific dynamics and characteristics of the production region. Furthermore, employment will not be evenly distributed across all income classes and some will benefit more from sugarcane ethanol expansion than others [31,32]. Hence, it is important to understand not only the net economy-wide impacts of expanded biofuel production, but also the distribution of these impacts. This information can help to identify socio-economic opportunities and threats of biofuel expansion for different regions and income classes. This is especially relevant for Brazil where inequalities between regions and income classes in society are large [33].

The direct, indirect and induced socio-economic impacts of bioenergy production can be assessed ex-ante by input-output (IO) analysis. IO analysis has been applied in a number of studies as a tool to quantify the socio-economic impacts of biofuel production, but these studies are often performed on a national level [27,34–36]. Souza et al. used a hybrid method of IO analysis and social life cycle assessment to differentiate impacts on different stakeholders (e.g. workers, consumers, society), but focuses on the national level. Thereby, they overlook regional differences within a country, such as the heterogeneity of the structure of the economy, and they mask the (uneven) distribution of socio-economic impacts within a country. Other studies have used regional IO analysis to remedy this drawback [38–40]. Although these studies consider a more local level, their disadvantage is that the study area is analysed as a separate entity, not taking into account the economic connections with other regions or the country as a whole. This makes it impossible to analyse spillover effects and to compare impacts between different regions. In addition, these studies estimate only net employment effects of bioenergy production, and do not differentiate between different types of labour based on skills or remuneration, although this may vary and contribute to inequality – an effect that would counteract meeting the SDGs.

A number of inter-regional IO studies has been performed specifically for the Brazilian sugarcane ethanol sector. In these studies, different levels of aggregation can be found. Studies that are performed on a macroregional level are based on a division of the country into two to five regions [41–44]. Zooming in on one or more of the 26 states of Brazil, increased the level of detail. For example, Moraes et al. [45] consider São Paulo state, Herreras Matínez et al. [46] analyse the North East of Brazil, and Compeán and Polenske [47] make a comparison between the North East and South East regions. In this study, a next step is taken by adding an additional level of detail by including microregions, a sub-state administrative level in Brazil, in an IO model.

Thus, the aim of this study is to compare the distribution of socio-economic impacts of sugarcane ethanol production expansion in Brazil on a microregional level, including the interregional effects. This paper zooms in on Piracicaba, Presidente Prudente and South West Goiás, three microregions in the Centre South of Brazil and considers effects on GDP, employment and imports related to the increased sugarcane ethanol production in 2030. To capture the effects on different types of labour, the distribution of employment by income class will be analysed.

To calculate the socio-economic impacts of biofuel production expansion, we couple the outcomes of the macro-economic MAGNET [48] model and the land use allocation model PLUC [49,50] to a new inter-regional IO model (modified from [51]). The combination of MAGNET and PLUC gives a spatially explicit distribution of sugarcane production and other land use in 2030. The region-specific characteristics of the economy are reflected in the inter-regional IO model that allows for variation between regions in the input and output of the economic sectors. These characteristics are further supplemented by region-specific cost structures of the sugarcane and ethanol industry, based on Jonker et al. [52].

2. Case study area

As a result of a policy-driven demand from abroad and a growing domestic market, Brazilian ethanol production is expected to expand significantly in the coming decades [9,11,53]. Within Brazil, sugarcane cultivation and ethanol production predominantly takes place in the Centre-South (CS) and to a lesser extent in the North East region (see also Section 3). As the growth is expected to primarily take place in the Centre-South region of Brazil [54,55], therefore this study focuses on this region. The Centre-South is generally favoured by higher R&D investments, more advanced technologies, better soil and climate conditions and consequently a higher productivity than the North East [56].

The effect of the sugarcane ethanol expansion is assessed for three microregions within the CS region: Piracicaba, Presidente Prudente and South West Goiás (see Fig. 1). Microregions are legally defined administrative areas that consist of a number of municipalities, e.g. São Paulo state consists of 645 municipalities distributed over 63 microregions [57]. The choice for these microregions was made based on expected future dynamics with regard to sugarcane cultivation area. *Piracicaba* is the smallest of the three microregions, but is has been an important and stable producer of sugarcane in São Paulo state over the past decades [58]. However, due to its relative hilliness not all areas are suitable for mechanised harvesting as required at the latest by 2021 under the State Law [59] and Agro-Environmental Protocol [60]. Therefore, the total sugarcane cultivation area in this region is not expected to expand further. The planted area of sugarcane in Piracicaba peaked in 2010 with a total area of 1700 km^2, and decreased to 1530 km^2 in 2014 [12]. *Presidente Prudente* and *South West Goiás* are expansion areas where the area of sugarcane production rapidly increased over the past years. Presidente Prudente is considered as one of the last available regions in São Paulo state that is suitable for large scale sugarcane expansion [61]. The total cultivated area of sugarcane in this microregion increased by 545% between 2000 and 2014 [62]. *South West Goiás* is relatively new to sugarcane production. Between 2000 and 2014 it has witnessed an sevenfold increase in the sugarcane area, reaching nearly 2500 km^2 [62], and a further expansion of sugarcane cultivation is expected to take place [63].

In addition to the variation in the sugarcane production and expansion potential, also the macro-economic structure of the regions differs. For instance, in South West Goiás more than a quarter of GDP comes from agriculture, in contrast to Piracicaba where it is only 3%.

Fig. 1. Map of Brazil with macroregions, states and the three selected microregions, based on the administrative map of IBGE [56,57].

These differences in the economic structure of the microregions will influence the effect of additional economic activity. Table 1 gives an overview of the characteristics of the microregions and their agricultural land use.

3. Methods

The impacts of an increased sugarcane ethanol production in Brazil on the socio-economic indicators GDP, employment and trade were calculated using an interregional IO model (see Fig. 2). This IO model was adapted for this study from the official IO tables from the Brazilian Institute of Geography and Statistics (IBGE) [69] and contains ten regions (Section 3.1). Three scenarios and a reference scenario for comparison were applied to account for uncertainty in future sugarcane and ethanol production technologies (Section 3.2). The scenarios were implemented in the IO model by changing the sugarcane and ethanol production technologies (Section 3.2.1) and varying the size of the shock. The size of the shock in each scenario and each region was determined using to the macroeconomic MAGNET model and the land use model PLUC (Section 3.2.2). The combination of these two models defined the agricultural production in each region, which served as an input to the IO model. In addition to the sugarcane production, the model shock also included the impact of the competition for agricultural land to accommodate the additional sugarcane production on the rest of the agriculture. A distinction was made between the *direct effects* (from the expansion of the sugarcane sector); the *indirect effects* (from those sectors delivering to the sugarcane and ethanol sectors); and the *induced effects* (from additional household income directly and indirectly earned from a sugarcane ethanol expansion and spent on consumer goods) [29]. The additional employment was disaggregated to twelve income classes.

3.1. Input Output model

This study used an initial inter-regional IO table for the year 2008 that was made available by the University of São Paulo (USP) [51]. In our IO model, the economies of the three microregions Piracicaba, Presidente Prudente and South West Goiás are disaggregated from the official national IO tables that are published by IBGE [70]. The method and the different data sources that are used to obtain an inter-regional IO table on state-level have been described by Guilhoto [71]. The three selected microregions were disaggregated from their respective states by estimating the monetary flows in the inter and intraregional matrices of the microregions. The estimation of these flows was based mainly on 1) statistical data on the level of microregions that are provided by IBGE: *Produção Agrícola Municipal* (PAM, municipal agricultural production) for the agricultural sector [62]; *Pesquisa Industrial Anual* (PIA, annual industry survey) for the industrial sectors [72] and *Pesquisa Anual de Serviços* (PAS, annual services survey) for the service sectors [73]); and 2) using cross-industry location quotients that are combined with the *Relação Anual de Informações Sociais* (RAIS, annual report of social information) [29].

The regional disaggregation that was used in this study distinguishes ten regions: three microregions we defined earlier (Piracicaba, Presidente Prudente and South West Goiás), the rest of their states (São Paulo and Goiás), the rest of the macroregions (South East and Centre

Table 1
General, economic, sugarcane cultivation and land use characteristics of the three selected microregions.

	Piracicaba	Presidente Prudente	South-West Goiás
General characteristics			
State	São Paulo	São Paulo	Goiás
Number of municipalities[a]	12	30	18
Total area (km^2)[b]	3700	18,000	56,000
Share of national population in 2012 (%)[c]	0.29	0.30	0.24
Economic characteristics			
GDP 2012 (billion USD)[d]	11	6.4	7.6
Share if national GDP in 2012 (%)[d]	0.37	0.28	0.32
GDP per capita 2012 (1000 USD)[e]	15	11	15
Contribution of agriculture to GVA in 2012 (%)[f]	3	8	28
Contribution of industry to GVA in 2012 (%)[f]	32	28	26
Contribution of services to GVA in 2012 (%)[f]	64	64	46
Sugarcane cultivation			
Planted area 2012 (km^2)[g]	1570	3140	1420
Average yield 2012 (t ha^{-1})[g]	77.0	70.0	81.9
Production value sugarcane 2012 (million USD)[g]	408	646	330
Land use			
Crop land 2012 (excluding sugarcane) (km^2)[h]	80	890	19,220
Cattle 2012 (1000 heads)[j]	157	1544	2601

[a] The division of microregions in municipalities follows the administrative division by IBGE [57].
[b] 2010 Demographic Census of IBGE [64].
[c] Total population in Brazil was 194,421,853 in 2012, data from IBGE [65,66].
[d] Total GDP in 2012 in Brazil was 2.47 trillion USD (2012 prices), data from IBGE [67].
[e] Calculated by dividing the regional GDP of the year 2012 (d) by the regional population of 2012 (c).
[f] GVA = Gross Value Added (GVA + taxes on products - subsidies on products = GDP), data from IBGE [67].
[g] Sugarcane data from Produção Agrícola Municipal, IBGE [62].
[h] Crop area without sugarcane is calculated as the total planted area of temporary crops minus the planted area for the sugarcane (g), data from IBGE [62].
[j] Pesquisa Pecuária Municipal, IBGE [68].

West), and the other macroregions (South, North, and North East including Mapito). A description of the IO tables and the associated equations for the IO analysis, following the IO literature [29,44], can be found in Appendix A1. The original IO table consisted of 56 sectors per region. However, for reasons of operability, the less relevant sectors with high similarities are grouped together, resulting in a total of 35 sectors in the final model (see Table A.1).

3.1.1. *Technology differentiated sectors*

An important deviation from standard IO models was the implementation of the *technology differentiated sectors* approach proposed by Cunha [74] and described in [44]. In classic IO models, each sector produces a single commodity and vice versa [29]. In this paper, we distinguished two variants: 1) a single commodity produced by multiple sectors (i.e. sugarcane from manual and mechanical harvesting) and 2) one sector producing multiple commodities (i.e. ethanol mills producing ethanol, sugar and electricity). This approach enabled us to include multiple inputs and outputs of the sugarcane ethanol industry.

3.1.2. *Employment distribution*

To explore the distribution of employment, different labour categories were distinguished in the IO model based on the level of income. This was done by dividing the total remuneration for each sector in every region into twelve income categories based on statistical data from the annual RAIS survey of 2008 of the Ministry of Labour and Employment [75]. The RAIS database was used to extract the number of employees and the average wages for each economic sector in each microregion specifically. The twelve income classes are expressed as the share of the minimum wage in Brazil (see Table A.2, Appendix). Employees in the lowest income category receive up to half the minimum wage in Brazil, while those in the highest income category receive more than twenty fold the minimum wage [75].

3.1.3. *Model runs*

The IO model was shocked with varying sugarcane production values (X), expressed in monetary terms. Normally, the exogenous variable in an IO analysis defining the model shock is the final demand (Y), while the production value is determined endogenously. Here another approach was taken to account for 1) the production volume under competition for land with other agricultural sectors and 2) reduced demand for fossil fuels as a result of the expansion of ethanol production. For the latter, the shock to the sugarcane production was

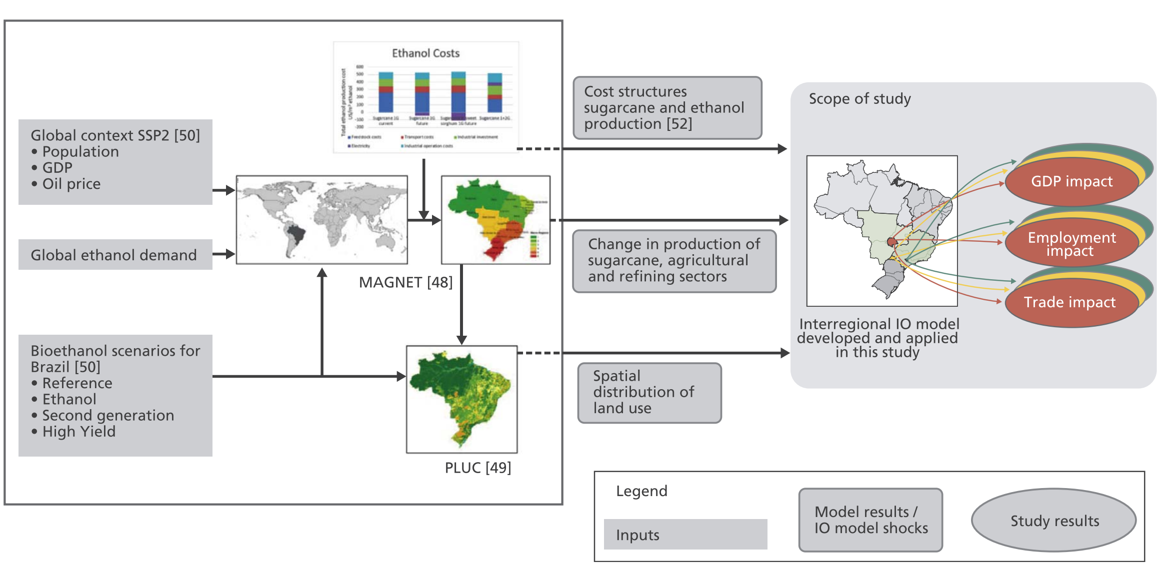

Fig. 2. Overview of the inputs to the models and the connection between them. The left hand side of the figure shows the inputs to MAGNET [48] and the PLUC model [49]. Outputs of these models are inputs to the IO model that is depicted in the shaded area on the right hand side of the figure. In each scenario the interregional IO model calculates the socio-economic impacts in Piracicaba, Presidente Prudente and South West Goiás.

accompanied by a negative shock to the refining sector to account for the decrease in fossil fuel demand from an increase in ethanol production. For the former, the effect of the sugarcane ethanol expansion on the other agricultural sectors was also included as a positive or negative shock, depending on the scenario (see Section 3.2.2).

The production values for sugarcane, agriculture and fossil fuels (see Section 3.2.1) were determined for all ten regions. To calculate the socio-economic effects all regions were shocked simultaneously, which gave the total effects of the sugarcane ethanol expansion. Next, the regions were also shocked one by one to establish the spill-over effects from one region to the others. Shocking the regions one by one isolated the effect of sugarcane expansion on that single region without including the effect from expansion in other regions. This shows how much of the economic effect remains in the region and how much leaks away. To calculate how well a region absorbs the economic effects from outside its own borders, we shocked all regions except for the region of interest. All impacts in that microregion that has no sugarcane production are the spill-over effects from outside its own borders.

3.2. Scenario approach

To compare the effects of sugarcane ethanol expansion on a microregional level, it is important to isolate the effect of the increase in ethanol production. In order to do this we used a *Reference* scenario that assumed no increase in worldwide ethanol demand compared to 2012 and was used as a contrast to the production expansion in the other scenarios. The *Ethanol* scenario assumed a high increase in worldwide demand for ethanol, leading to an increase in ethanol production from 24 billion litres in 2012–54 billion litres in 2030 in Brazil. These two options are based on the forthcoming work of Van der Hilst et al. [50] and apply the same assumptions on socio-economic development in terms of population and economic growth, and the Brazil-specific issues such as mechanisation, yield growth, technological development etc.

As land resources are not unlimited, expansion of sugarcane can displace the production of other sectors and thereby influence the socio-economic impacts. Therefore, we also considered two additional scenarios that focus on the reduction of agricultural land demand in the case of extra ethanol demand. The *2G* scenario assumed a transition towards second-generation sugarcane ethanol production and twice as high yield growth in the sugarcane sector (1.6% per year instead of 0.8%) compared to the *Reference*. The *High Yield* scenario assumed productivity increases in the entire agricultural sector would develop twice as fast as in the other scenarios (1.4–2.8% per year, depending on the crop). This reduces the competition for land between food, feed and fuels. In Table 2, an overview of the scenario parameters is provided. These parameters were assumed to be constant for the Centre South and the microregions, unless specified differently in this table.

3.2.1. Implementation of technology differentiated sectors

To implement the scenarios in the model, we first adapted the IO model, to account for the changing technologies. The current and future cost structures of the sugarcane cultivation and harvesting, and of the ethanol sectors were based on the work of Jonker et al. [52]. They have estimated the development in production costs in the Brazilian ethanol sector. We used the cost structures of cultivation and manual and mechanical harvesting, including trash collection for second generation ethanol production, and the ethanol production technologies that were defined in Table 2. To align these cost structures with the rest of the IO model, the cost breakdowns from Jonker et al. were converted to the sectors of the IO model for each region, matching them to the 35 sectors in the ten regions of the original IO matrix. This was done by multiplying the cost structures with the technical coefficients of the original IO model.

We used region and scenario-specific parameters for the ratio between the different inputs and outputs in the two *technology differentiated sectors* (i.e. manual and mechanical harvesting, and ethanol, sugar and electricity production). The ratio between mechanical and manual harvesting was defined based on [50] and is presented in Table 2. To calculate the ratio between the outputs of the ethanol sector (ethanol, sugar and electricity), the production of each of the three products in each microregion was required. The first step was to disaggregate the ethanol and sugar production to the microregions. For 2012, the ethanol and sugar production per state were taken from UNICA [76] and disaggregated to the microregions based on their share in the sugarcane production of their state. To obtain the disaggregated ethanol production in 2030, we first calculated for each region the ratio between the share of the ethanol production in 2012 [76] and the share of the sugarcane production in 2012, this showed whether a region produces more or less ethanol than can be expected. Then the share of the sugarcane production in 2030 in each region was multiplied by the nationwide projected ethanol production in 2030 to obtain the expected ethanol production in each region. Finally, the results from the previous steps were multiplied to account for regional differences. A similar approach was used to calculate the 2030 sugar production. The electricity production per tonne sugarcane was derived from the model of Jonker et al. [52] and assumed equal for each region. The output parameters for the technology differentiated sector were then calculated as the share in the total revenue, based on basic prices (see Table A.3).

3.2.2. Model shock

The production value (X) with which the IO model is shocked in each scenario consists of three components: the sugarcane production, the reduction in the refining sector and the effect on the other crops and the livestock sector. The production value was calculated as the production in each sector multiplied with the basic price, to obtain the monetary value of the shock. All basic prices in this study are presented in Table A.3.

The calculation of the sugarcane production in each region for each scenario started from the sugarcane area in 2012 per microregion from IBGE [62]. The growth until 2030 was derived from the land use allocation by the PC raster Land Use Change (PLUC) model [49]. The PLUC model used the output of the CGE model MAGNET, which calculates the worldwide macro-economic responses to changes in the demand for ethanol considering competition for land and resources towards the future [77]. MAGNET reports the outcomes from Brazil on the level of the macroregions, the PLUC model then allocates the regional land use spatially-explicitly on a five-by-five kilometre grid cell level. Sugarcane productivity was extrapolated using the scenario assumptions by Van der Hilst [50] with yield increases of 0.8–1.6% per year.

The rest of the agricultural sector consisted of two sectors in the IO model: other crops and livestock. To calculate the production value of the non-sugarcane crops for each scenario, we first calculated the crop area per region for paddy rice, wheat, coarse grains, oilseeds, fruit and vegetables, fibre crops, and ‘other crops’ based on the results of MAGNET and PLUC. Yield growth of these crops was expected to follow the assumptions for MAGNET of Van der Hilst [50] (0.7–1.4% per year, 1.4–2.8% in the *high yield* scenario). The production in livestock sector was calculated from the product of the livestock area the density. For livestock, both intensive (pasture) and extensive (rangeland) livestock areas in 2012 and 2030 were given by PLUC. Current densities, 1.76 and 0.52 heads per hectare, were assumed to be the same throughout Brazil [50]. The yield growth is presented in Table 2; resulting in densities of 1.85 (intensive) and 0.69 (extensive) in 2030 in the *Reference* and *Ethanol* scenarios. In the *High Yield* scenarios the livestock density increased to 1.95 (intensive) and 0.91 (extensive) in 2030.

The expansion of domestic ethanol consumption was 24 billion litres between the *Reference* scenario and the *Ethanol* scenarios in MAGNET. This additional consumption was assumed to replace an energetically equivalent amount of gasoline (i.e. 1 l of ethanol replaces 0.66 l of gasoline [78]). This was included as a negative shock to the

Table 2
Input parameters and assumptions for the 2012 reference scenario and the four 2030 scenarios. The top presents parameters that are equal for all three microregions, the others are region specific.

	Unit	2012	Reference	Ethanol	Ethanol: 2G	Ethanol: High Yield
Ethanol production[a]	10^9 l yr^{-1}	24	28	54	59	55
Sugar production[b]	10^6 t yr^{-1}	38	67	67	70	68
Ethanol yield from cane[c]	l t^{-1}	44–81	70–128	70–128	93–170	70–128
Ethanol technology[d]		1G 2012	1G 2030	1G 2030	1–2G optimised + use of trash	1G 2030
Annual sugarcane productivity increase[d]	%		0.8	0.8	1.6	1.6
Annual livestock productivity increase (intensive/ extensive)[e]	%		0.28 / 1.58	0.28 / 1.58	0.28 / 1.58	0.56 / 3.16
Livestock productivity 2030 intensive/extensive	Heads ha^{-1}		1.85 / 0.69	1.85 / 0.69	1.85 / 0.69	1.95 / 0.91
Annual productivity increase rest of agriculture[f]	%		0.7–1.4	0.7–1.4	0.7–1.4	1.4–2.8
Mechanical harvesting[g]	%	65	95	95	95	95
Net electricity production[h]	kWh t^{-1} cane	17.4	6.3	6.3	0	6.3
Microregion specific scenario assumptions and inputs						
Sugarcane area	km^2	PIR: 2 100 PP: 800 SWG: 3300	PIR: 1 975 PP: 775 SWG: 7450	PIR: 2 125 PP: 130 SWG: 12,900	PIR: 2100 PP: 1125 SWG:1145	PIR: 1950 PP: 750 SWG:6800
Other crops	km^2	PIR: 0 PP: 450 SWG: 19,750	PIR: 0 PP: 480 SWG:19,000	PIR: 0 PP: 125 SWG:13,000	PIR: 0 PP: 477 SWG: 19,000	PIR: 0 PP: 375 SWG:14,500
Livestock area	km^2	PIR: 150 PP: 13,100 SWG:17,000	PIR: 0 PP: 13,500 SWG: 15,500	PIR: 0 PP: 13,500 SWG:15,500	PIR: 0 PP: 13,500 SWG:15,500	PIR: 0 PP: 13,000 SWG:15,400
Sugarcane yield	t ha^{-1}	PIR:77 PP: 70 SWG:82	PIR: 89 PP: 81 SWG:95	PIR: 89 PP: 81 SWG:95	PIR: 102 PP: 94 SWG:109	PIR: 102 PP: 94 SWG:109
Ethanol yield from cane	l t^{-1}	PIR /PP: 58 SWG: 73	PIR /PP: 92 SWG: 116	PIR /PP: 92 SWG: 116	PIR /PP: 123 SWG: 154	PIR /PP: 92 SWG: 116
Share sugarcane for ethanol	%	PIR /PP: 45 SWG: 73	PIR /PP: 31 SWG: 51	PIR /PP: 45 SWG: 73	PIR /PP: 47 SWG: 70	PIR /PP: 46 SWG: 74
Ethanol production	10^6 l	PIR: 320 PP: 585 SWG: 623	PIR: 381 PP: 717 SWG: 1781	PIR: 592 PP: 1736 SWG: 4454	PIR: 856 PP: 1578 SWG: 3699	PIR: 685 PP: 1760 SWG: 4632
Sugar production	10^3 t	PIR: 864 PP: 329 SWG: 373	PIR: 1387 PP: 2609 SWG: 2612	PIR: 1159 PP: 3399 SWG: 2402	PIR: 2487 PP: 4586 SWG: 2801	PIR: 1386 PP: 3561 SWG: 2502

[a] Values from MAGNET model.
[b] 2012 data from UNICA for harvest season 2012/2013 [76], growth calculated from MAGNET model results.
[c] Reference 2012: for each state the sugarcane required for the ethanol production was calculated by multiplication of the sugarcane production and the share of the sugarcane that was used in 2012/2013 by the ethanol industry [79]. Dividing the ethanol production per state [76] by this number gave the ethanol yield in each region. For the macroregions in the North, where no division data were available, the national average of the equal division between sugar and ethanol was used. For the microregions, the average productivity of their state was used. Scenarios 2030: the productivity was assumed to increase similarly in each region (1.58% per year for the first generation scenarios; 2.1% per year for the second generation scenario).
[d] Terminology refers to the work of Jonker et al. [52]. For the cost structures we followed their default assumptions in which the size of a plant was 1230 t/hour for first generation and 156 for second generation. Adaptations were made to the sugarcane cultivation, where for each region the sugarcane yield was changed to the yield in this table, land prices per region were varied as a share of land prices in Sao Paulo, based on [80].
[e] We followed the assumptions that were used for MAGNET/PLUC [50].
[f] Following the assumptions for MAGNET/PLUC that use crop-specific yield growth percentages for the periods 2010–2020 and 2020–2030. The yield growth in the *High Yield* scenario was double the yield growth in the other scenarios.
[g] taken from the assumptions for MAGNET [50], here the mechanisation rate was assumed to increase to 95% in most regions, only in the North East this was somewhat lower.
[h] Derived from the outlook for sugarcane ethanol production of Jonker et al. [52] using the appropriate ethanol production technology for each scenario.

refining sector.

The IO model was shocked with the production values of the sugarcane, other crops, livestock and refining sectors. These sectors are assumed to be directly affected by the expanding demand for sugarcane ethanol. For the other sectors no direct change, i.e. ceteris paribus, was assumed. This enabled us to isolate the effect of the sugarcane ethanol production expansion on the rest of the economy.

The production value of sugarcane in each scenario was applied as a shock. For the production in the rest of the agriculture and the refining sector, we applied another approach. For these sectors we calculated the shock as the revenue difference between the *Reference* and the three *Ethanol* scenarios in 2030, in order to isolate the effect of the additional ethanol production.

4. Results

Using the inter-regional IO model we calculated the impacts of an increase in Brazilian ethanol production from 28 billion litres in the *Reference scenario* to 54–59 billion litres on the socio-economic indicators GDP, employment and trade. The results include the effect of reduced fossil fuel production, the displacement of other agricultural land uses due to additional sugarcane ethanol production and the indirect and induced effects in the other economic sectors.

4.1. Overall results

The growth in sugarcane ethanol increases GDP and employment in Brazil. Table 3 shows the results for the three microregions and the whole country in 2012 and 2030 (full results are presented in Tables A.4-A.8 in the Appendix).

The low increase in ethanol production in the *Reference* scenario leads to a net GDP growth of 6.4 billion USD in 2030 or 0.25% of the 2012 GDP. All three selected microregions see an increase in GDP coming from sugarcane ethanol in 2030 compared to 2012. Despite a

Table 3
Total contribution to GDP, employment and import of sugarcane in Brazil in the reference situation and in 2030, by region.

	Piracicaba	Presidente Prudente	Southwest Goiás	Brazil
Contribution to GDP (million USD_{2012})				
2012	223	308	174	17,078
Reference	326	464	579	24,514
Ethanol	316	629	441	27,144
Contribution to employment (1000 full time equivalent, fte)				
2012	11	20	14	988
Reference	18	36	52	1524
Ethanol	15	36	−19	1578
Contribution to imports (million USD_{2012})				
2012	22	24	12	1886
Reference	36	39	46	3107
Ethanol	28	33	−23	2626

slight decrease in the sugarcane area in the microregions in São Paulo in the *Reference* scenario, the contribution to GDP increases. This is because technological progress in sugarcane conversion and increased yields lead to an increase in ethanol production in the microregion. South West Goiás is a growth region, and doubling the sugarcane area between 2012 and 2030 increases the contribution of sugarcane ethanol to the regional economy to 7% of the 2012 GDP in the *Reference* scenario.

An additional production of 26 billion litres ethanol in Brazil in 2030 in the *Ethanol* scenario compared to the *Reference* scenario increases the nationwide GDP by a further 2.5 billion USD. This includes the effect of displacement of other agricultural production and of fossil fuels, which reduces the economic benefits of sugarcane ethanol expansion. The GDP effect increases significantly in Presidente Prudente because of the additional sugarcane ethanol production. In South West Goiás the increase in sugarcane area in the *Ethanol* scenario leads to a decrease in other agricultural production. As a result the GDP growth in 2030 is 24% (138 M USD) lower in the *Ethanol* scenario than in the *Reference*. In Piracicaba no other agricultural activities are displaced as these were too small to be included in the land allocation of the PLUC model. The small decline in GDP growth between the *Reference* and *Ethanol* scenario can be attributed to a slightly increased spill-over effect. This means a larger proportion of the inputs for the sugarcane ethanol production is supplied from outside the region, so in the *Ethanol* scenario Piracicaba benefits less from the sugarcane and ethanol production in the region than in the *Reference* scenario.

The sectors that contribute most to the GDP growth of sugarcane ethanol expansion in 2030 are sugarcane, ethanol and sugar production (see also Fig. 6). The only other important sectors in the three microregions are the transport sector and financial services. The importance of these sectors for the economy is region specific, and their contribution to GDP varies across regions.

The employment related to sugarcane ethanol production in Brazil, including the indirect and induced effects, grows from nearly 1 million in 2012 to around 1.5 million fte in 2030. In Piracicaba and Presidente Prudente, the effects on employment are comparable to those on the GDP. However, the large increase in the GDP effect in the *Ethanol* scenario in Presidente Prudente is not translated into an equivalent rise in employment. This can be explained by the labour intensity of agriculture. Ethanol and sugar production are less labour intensive per unit of GDP than the agricultural activities that are displaced. This is also well reflected in South West Goiás where employment falls (i.e. sectors outside sugarcane ethanol see a decline in employment that is not compensated by the increase from sugarcane ethanol production). The employment effect per unit of ethanol is lower in the three selected microregions than in the rest of Brazil (Table 4). The effect in South West Goiás is lower than in the two microregions in São Paulo as the decrease in other agricultural production is much larger in the former. The nationwide employment decrease resulting from the reduced

Table 4
Net employment impacts (fte Ml^{-1} of ethanol produced) in each region. This also includes the effect on the rest of agriculture and fossil fuel production.

	Piracicaba	Presidente Prudente	South West Goiás	Brazil
2012	35	34	23	43
Reference	47	50	29	54
Ethanol	25	21	−4	29

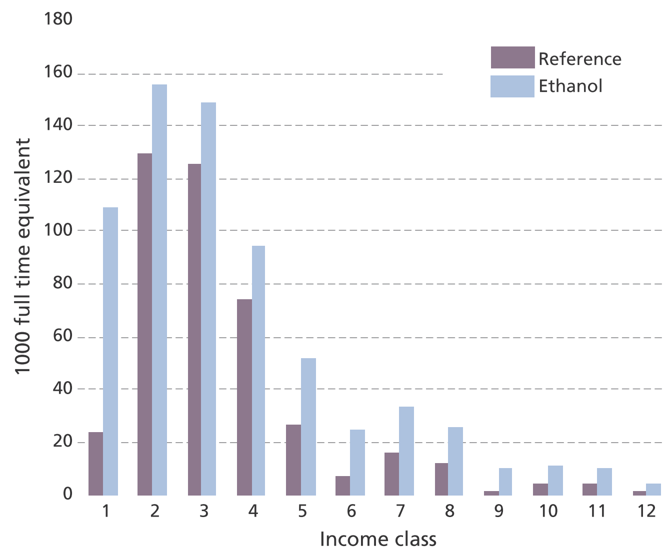

Fig. 3. Total employment increase in 2030 compared to 2012 in each income category in Brazil for the *Reference* and *Ethanol* scenarios. The pattern is comparable for the microregions.

demand for fossil fuels in 2030 is just below 7500 fte. It is mostly concentrated in São Paulo and the rest of the South East, where the refineries are situated. The effect in the three microregions is negligible at less than 100 fte.

In the *Reference* scenario, almost half of the additional nationwide employment is in the sugarcane sector. This is comparable in Piracicaba and South West Goiás; in Presidente Prudente it is 70% because a relatively large part of the supplies are from other regions and it supplies little to other regions. 75% of employment in the sugarcane sector is in income classes 2 and 3, this means most additional employment is in the lowest income classes (see Table A.2 in the Appendix). Fig. 3 shows the employment effect for Brazil, which is similar for the three microregions. The high share of employment in the lower income classes also means its benefits are mostly retained there. While additional benefits at this level are positive, this does not contribute to a reduction in income equality.

The *Reference* scenario includes a projected export of 2.9 billion litres of ethanol, increasing to 4.6 billion litres in the *Ethanol* scenarios. The imports to Brazil are presented in Table 3. The net trade balance is negative in the *Reference* scenario: − 1.4 billion USD. In the *Ethanol* scenario the trade balance is slightly positive, at USD 39 million. The regional differences in the changes to imports show the same trend as the GDP effect. The negative effect of imports in South West Goiás is caused by the decrease in the other agricultural sectors that require fewer imports in 2030.

4.2. Direct, indirect and induced impacts

The majority of GDP and employment impacts in the microregions are directly related to the expansion of sugarcane and ethanol production (see Fig. 4). The indirect effects, the additional economic and employment growth as a result of supply to the direct sectors, boost the GDP and employment further and are responsible for up to 25% of the

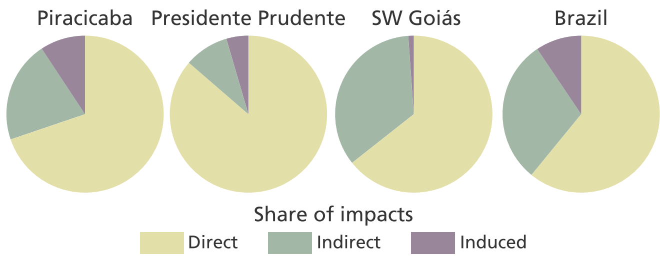

Fig. 4. Division of the absolute direct, indirect, and induced GDP effects in the three microregions and Brazil in the *2030 Ethanol* scenario. The picture is comparable for the other scenarios.

impacts. The most important sectors where these indirect effects occur are commerce, transport, business services and the financial sector. These indirect effects on GDP and employment are substantially smaller than the direct effects, but the indirect employment is found in the higher income classes. In Piracicaba, the services and industry sector are much more important than in the other two regions (see Table 1) as a result, more indirect effects occur in this region, mainly in the commerce, transport and agricultural chemicals sectors.

Like the indirect effects, the effects induced in the rest of the economy are relatively small in the three microregions. These are mostly in services and intermediary financial services in Piracicaba and Presidente Prudente. In South West Goiás most effects are induced in commerce and transport. A disproportionally large share of the induced impacts in the selected microregions is in low earning sectors.

4.3. Spill-over

To quantify the economic interconnectedness of the regions, the spill-over effects from one region to another are assessed. Somewhat less than a third of the GDP effect in Piracicaba is the result of sugarcane production outside its own borders (Fig. 5, right). In the *Ethanol* scenario, even without sugarcane expansion in Piracicaba itself, expansion in the rest of the country would add 98 million USD (or 1.3%) to the GDP and 4300 jobs (0.8% of total population) in the microregion. Especially the transport sector would benefit from this. The other two microregions benefit much less from the sugarcane ethanol expansion outside the region itself. This is because Presidente Prudente and South West Goiás are less traditional sugarcane regions than Piracicaba and will therefore have a less well developed industry for goods and services to supply the sugarcane and ethanol sectors.

Table 5
Results for the three *Ethanol* scenarios in 2030. The scenarios include an ethanol production of 55–59 billion litres and include different approaches to limit land use.

	Piracicaba	Presidente Prudente	Southwest Goiás	Brazil
GDP (million USD_{2012})				
Ethanol	316	629	441	27,144
Ethanol: 2G	563	829	1100	39,539
Ethanol: HY	454	836	1031	43,993
Employment (1000 fte)				
Ethanol	15	36	−19	1578
Ethanol: 2G	32	59	81	2312
Ethanol: HY	27	65	77	3695
Imports (million USD_{2012})				
Ethanol	28	33	−23	2626
Ethanol: 2G	45	46	57	3832
Ethanol: HY	46	62	63	5163

The spill-over from the microregions to the rest of the country is similar for the three microregions. Around half of the total regional GDP effect and 60% of the employment effect of the sugarcane production in the region occurs inside the region where the sugarcane ethanol is produced, the rest spills-over to other regions (Fig. 5, left). The largest share of the spill-over effect is to the rest of the state in which the microregion is situated. Despite being located outside São Paulo state, the amount spilled over from South West Goiás to the rest of Goiás is almost equal to the spill-over to São Paulo, where the sugarcane and ethanol industry are concentrated. The spill-over effect from Piracicaba and Presidente Prudente to South West Goiás is almost zero. In the state São Paolo mainly the transport (39%), financial services (33%) and machinery production (11%) contribute to the GDP growth.

4.4. Scenarios

Decreasing land use for sugarcane production in the *2G* and *High Yield* scenarios increases the GDP and employment growth compared to the *2030 Ethanol* scenario (see Table 5 and Fig. 6). Higher yields in the sugarcane and ethanol production reduce the competition for land, which means the land can accommodate both an expansion in sugarcane and other agricultural products. This leads to higher employment and economic growth in Brazil.

The effects of the two scenarios differ for the three microregions. For GDP and employment, Piracicaba and South West Goiás see a larger increase in the *2G* scenario than in the *High Yields* scenario. In contrast, in Presidente Prudente and the rest of the country the impacts of the *High*

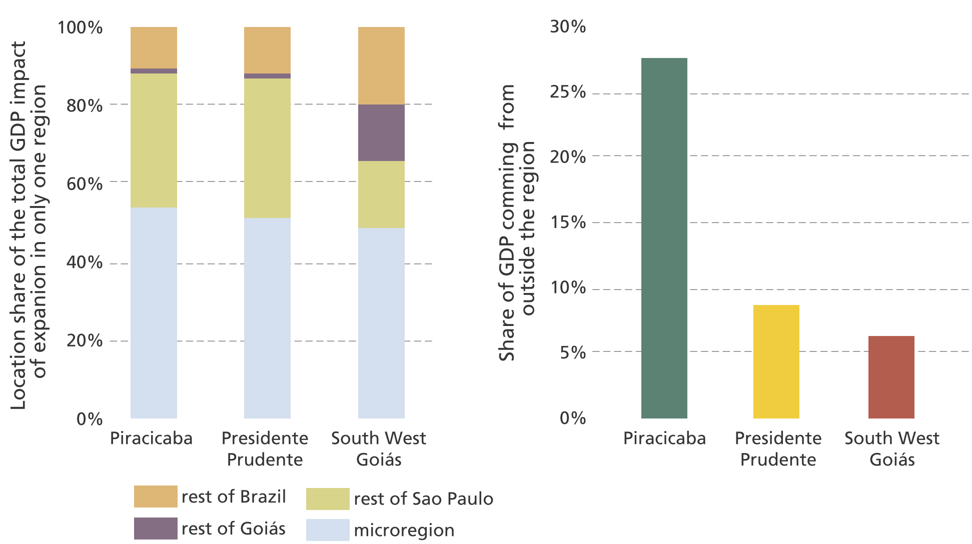

Fig. 5. (left) Location of the total GDP impact if only that microregion would produce sugarcane (right) Share of the GPD effect (expressed as share of GDP in Table 3) that is spilled-over to the region from outside its borders. Results presented for the *2030 Ethanol* scenario, similar patterns occur in the other scenarios.

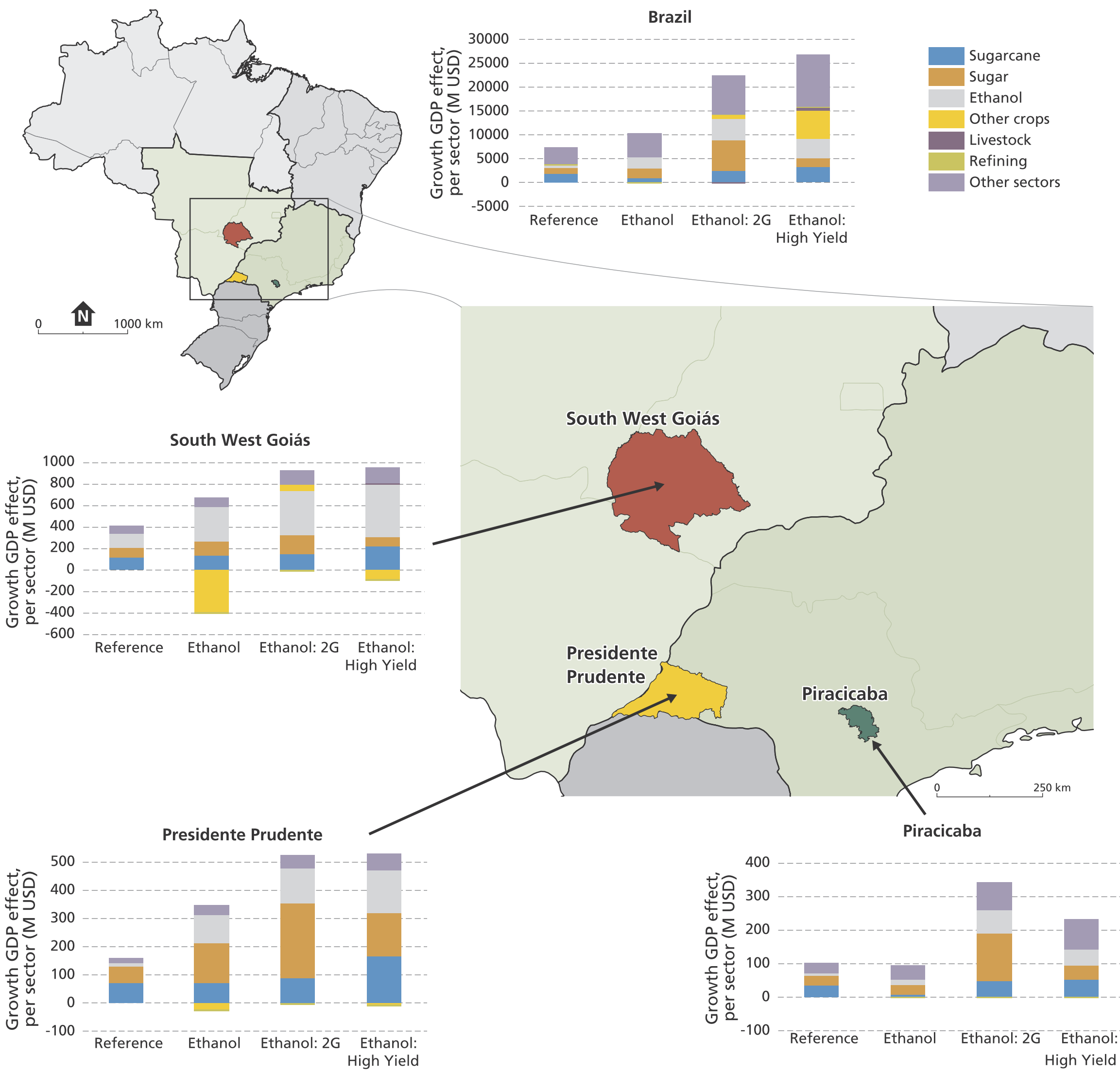

Fig. 6. Contribution of the sectors to the GDP growth compared to 2012 in each region and each scenario in 2030.

Yields are larger than in the *2G* scenario. This means in the first two microregions an increase of ethanol from each ton of sugarcane is more profitable than a yield increase on agricultural land. The cause of these differences lies in the structures of the regional economies. Piracicaba has little non-sugarcane agricultural land, so increased productivity of other crops and livestock on these lands has little effect. Despite the ethanol and sugarcane industry in South West Goiás benefiting more in the *High Yield* scenario compared to the *2G,* the rest of the agriculture and the sugar sector perform well in the *2G*, making this the most profitable scenario. The allocation of the employment effect to the to the twelve income classes shows a similar picture in the *2G* and *High Yield* scenarios as in the other two scenarios (see Fig. 3). The majority of the employment effects remains concentrated in the lowest income classes.

5. Discussion

5.1. Comparison with literature

The previous section presented the outcomes of an IO-model that was used to calculate the socio-economic impacts in 2030 in Brazil of sugarcane ethanol production expansion. The results presented here on a microregion level cannot be compared directly with other studies as this is the first study that considers these microregions. It is however possible to compare our results to others on a higher aggregation level. This shows our results compare well to previous findings.

The ratio between the size of the shock to the sugarcane sector and the total GDP impact in Brazil is in the range of 1.4 (*Reference 2030*) to 3.0 (*2G*). Watanabe et al. (2014) [81] using an IO model for 2009 found an economy-wide impact in Brazil of USD 1.6–2.2 for each dollar increase in ethanol demand, considering various technological set-ups (first generation, optimised first generation and mix of first and second generation). The range we calculated is larger as we also included a shock to the rest of the agriculture and the refining sector, that were not included by the previous study.

Estimates on the employment in the sugarcane ethanol industry in Brazil in 2012 vary around 1–1.1 million [10,24,82]. This estimate is similar to our estimate of 0.99 million. Moraes (2013) [83] presented a separate estimate for the sugarcane sector of 365 thousand jobs in 2011, based on RAIS data. This is comparable to our 2012 result of 385 thousand.

Compared to other sources of bioenergy, the employment effect of sugarcane production for ethanol is quite high, in 2012 in Brazil we found 2000 fte PJ^{-1}, of which 1500 were included in the direct effects. This is outside the range of 80–800 jobs PJ^{-1} that Wicke et al. found in studies of other energy crops [27]. However, our high value is slightly distorted as it is for a multi-output system with the outputs sugar and ethanol. Deducting the employment for sugar production and the share of the sugarcane that is not for the ethanol production reduces the estimate to 825 fte PJ^{-1}. The estimate of 1500 fte PJ^{-1} is comparable to the analysis of Herreras et al. [46] for sugarcane ethanol in the North East of Brazil. Their results show an employment intensity of ethanol production of 1350 fte PJ^{-1} in 2010.

The results for the microregions showed a positive impact of sugarcane ethanol expansion on GDP growth and employment in Piracicaba, Presidente Prudente and South West Goiás. This corresponds with the finding of Walter et al. [17] who showed that, on average, municipalities in São Paolo State with sugarcane production score higher on the human development index (HDI) than those without sugarcane production. Furthermore, Machado Gerber et al. [84] performed a statistical analysis of the socio-economic development of the same three microregions between 1970 and 2010. This analysis showed that sugarcane production correlates positively with socio-economic development.

5.2. Input output model

This research used a mixed-technology inter-regional input-output model to quantify the socio-economic impacts and their regional distribution, differentiated across income classes of biofuel expansion in Brazil in 2030. The use of an IO model has some inherent limitations [27,46,85]. These drawbacks include linearity of the model (i.e. the model works with fixed ratios; no economies of scale are considered), fixed prices and no competition for production factors. An IO model is a static model, and the linkages between economic sectors and regions are assumed to remain constant between 2008 and 2030, following the Ceteris Paribus principle. In reality, no changes in the economic sectors are unlikely, but it is inherent to the use of IO models. The advantage of not including structural economic changes is that the effects of sugarcane ethanol expansion can be isolated. To slightly remedy the effects of the rigid structure of the IO model, the technical coefficients of the sugarcane and ethanol sectors were variated between the scenarios, based on the work by Jonker et al. [52] to reflect technological progress and learning in these two important sectors.

As we use a mixed-technology IO model we can distinguish between manual and mechanical harvesting. However, there is only one labour category in the cost structures in the IO-model and the division to the 12 income classes is a post-analysis, following a fixed sector-specific ratio. Consequently, the agricultural employment in 2030 is still divided proportionally to the same labour categories as in 2012. This does not capture a redistribution of the income classes that is likely to occur with a switch to mechanical harvesting. Although a switch from manual to mechanical harvesting has a negative effect on employment, those employed need to be better skilled which affects the wage level [10]. Regional variation in wage level could also mean similar employment would be in different income classes in different regions; this is not included in the model. However, despite this, the pattern that most employment will be in the lowest income classes is still valid.

Although the IO model can capture the impacts on indicators that can be quantified, some not-quantifiable indicators are also important for the socio-economic situation. An example of these are the working conditions in manual harvesting that are currently very poor. It can be expected that banning sugarcane burning and technological development will improve working conditions and decrease accidents [10,24,86]. Currently many harvesters have almost no education [86], and as we see a decrease in the lowest income class in the *Reference* scenario, it remains to be seen to what extent these people can benefit from the additional employment in higher income classes as operating more advanced technologies requires better educated employees [37]. New initiatives such as the Renovação Project retrain sugarcane harvesters to other occupations in order to limit the negative employment impacts of the transition to mechanical harvesting [87].

The model does not include the effects of population growth and migration. As the supply of manual labour in São Paulo state is too small during the harvest season, it is common for people living in poorer areas, such as the North East, to move to São Paulo state to work as day labourer in the sugarcane sector [46]. This migration can put pressure on the local communities [17], which is not reflected in economic models.

5.3. Input data

The input output table that we used as a basis for our model was a disaggregated version of the Brazilian IO table in which we implemented new technical coefficients for the sectors related to sugarcane ethanol. These steps add detail to the analysis at a cost of increased uncertainty. The IO tables are based on data from 2008 as more recent data were not available. The cost structures of the sugarcane and ethanol sectors that were taken from the work of Jonker et al. [52] assume an average mill for sugarcane processing, whereas in reality there will be multiple types in operation. Furthermore, the assumed electricity output of the mills in 2030 in this study is relatively low compared to other studies (e.g. [88,89]). Higher electricity revenues would increase the total GDP and employment effects of the ethanol production expansion, but the effect here is negligible.

The final results are very sensitive to the sugarcane production in each region in the initial year. We used the area and production data from IBGE and calculated the growth in sugarcane area for each region from PLUC data for that region, starting in 2012. Although on macroregional level, the difference between PLUC and IBGE is small, on microregional level these changes are significant. Especially in Presidente Prudente the difference is large (800 km^2 in PLUC and 3 140 km^2 according to IBGE). This has a major impact on the final results as the impact of sugarcane in that microregion in the *Ethanol* scenario decreases by 72%. Despite the effect on the absolute economic contribution of sugarcane expansion, the relative economic growth in the *Ethanol* scenario compared to the *Reference* remains unchanged. However, the large differences between the official IBGE data and PLUC that based the baseline on satellite data emphasise the need for more reliable spatially explicit data on current sugarcane production in Brazil.

A majority of the effects of sugarcane ethanol expansion in Brazil are direct effects, this means the assumed location of the sugarcane expansion is important. The MAGNET model distributed the sugarcane area over the macroregions; the PLUC model in turn was used to calculate the spatial explicit distribution over the microregions. However, the MAGNET-PLUC framework only provides the regional distribution of the sugarcane production. It does not provide information on the ratio of sugar and ethanol production in a region, which is required for the IO model. This meant assumptions had to be made for this ratio. However, the impact of these assumptions on total GDP and employment are negligible, only the distribution between the sectors and income classes are affected.

6. Conclusions

The aim of this study was to analyse the distribution of socio-economic impacts of sugarcane ethanol production expansion in Brazil including the interregional effects on a microregional level. For this, we used an inter-regional mixed-technology input-output model and separated the employment effect for twelve income classes. We used a *reference* scenario with a small increase in sugarcane ethanol production in 2030 and three scenarios with a high increase (*Ethanol*) of which two additionally include the implementation of measures to reduce the competition for land (*2G* and *High Yield*).

The increase in 2030 sugarcane ethanol production from 28 billion in the *Reference* scenario to 54 billion litres in the *Ethanol* scenario results in a nationwide growth in GDP (2.6 billion USD) and employment (53,000 fte), despite a reduction in fossil fuel demand and displacement of livestock and other crop production. The three microregions show a more mixed picture: Piracicaba sees a small decrease in GDP and employment, whereas Presidente Prudente sees a large GDP increase, but no employment increase and both indicators decrease in South West Goiás. The effect of *2G* or *High Yield* is much more uniform across the microregions and impacts as it increases the GDP, employment and imports.

The mixed picture in the microregions is not only caused by the difference in potential to expand sugarcane production, but also by the structure of the economy. The sugarcane production in Piracicaba is well developed and has little room for expansion, but the microregion benefits most from expansions outside its own borders. Presidente Prudente and South West Goiás are projected to significantly expand sugarcane production, but as a result of displacement of other agricultural activities, the GDP and employment effects are negative in South West Goiás, and in Presidente Prudente only the contribution to GDP is positive. Despite a nationwide GDP and employment increase with increasing ethanol production these benefits are not uniform throughout the country.

The employment effects are not only unequally distributed geographically, but also unequally distributed over the various income classes, as over 60% of employment impacts from sugarcane ethanol production is found in the income classes lower than twice the minimum wage. This unequal distribution is similar for the three regions.

The socio-economic impacts of an expansion in sugarcane ethanol production that we presented here can be affected by policy measures. For example, the analysis of direct, indirect and induced impacts shows that GDP effects from sugarcane ethanol expansion in Presidente Prudente and South West Goiás are primarily direct. Indirect and induced impacts are very small. Similarly, the analysis of the spill-over effects shows that nearly 50% of the effects occur outside the region where the expansion occurs. Thus, regional policies to stimulate the economic sectors that deliver to the sugarcane and ethanol sectors (such as for machinery production) could help reap more of these benefits in the region.

The impacts and the ability to benefit socio-economically from the sugarcane ethanol expansion depend on characteristics of the economy of the region itself. This means that an assessment of the location of sugarcane expansion is not only important for sustainability from an environmental perspective, but also from a socio-economic perspective. These two types of distribution (spatial and over the income classes) are both important issues for sustainable development. Future research could point out the (policy) drivers in each region that caused the differences in the economic structure of the regions. This understanding can help steer sugarcane ethanol production towards more positive socio-economic effects. This can be important for industry and policy-makers on national and subnational levels who want to increase the benefits of sugarcane ethanol expansion. The combination and trade-offs between environmental and socio-economic impacts can also be important for sustainability certification, where both pillars of sustainability are considered. The regional differences also mean that country level analyses of the socio-economic impacts of sugarcane ethanol expansion are not sufficient as microregional level analysis provides insights that remain hidden otherwise.

Acknowledgements

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Appendix

IO matrix

The interregional IO table (matrix Z) is built up from the inter- and intra-regional tables ($Z^{n,n}$) of these ten regions, and can be expressed as:

$$Z = \begin{bmatrix} Z^{1,1} & \cdots & Z^{1,10} \\ \vdots & \ddots & \vdots \\ Z^{10,1} & \cdots & Z^{10,10} \end{bmatrix}$$

Matrix $Z^{1,1}$ represents the intraregional flow of goods and services in region '1'. The interregional trade flows are accounted for by elements in the off-diagonal matrices. For example, the elements in the matrix $Z^{1,10}$ denotes a trade flow of goods and services originating in region 1 towards region 10 [29].

Dividing the monetary flows in each sector of each region (z_{ij}) by the total output (x_j) of that sector gave us the technology matrix (A). The elements (a_{ij}) then represent the technical coefficients. Estimations of the monetary flows are unique for every sector of each region in the model, and result in an estimation of region-specific intraregional and interregional technology matrices in which the regional differences in the economic structures are reflected.

The elements of the corresponding technology matrices are calculated as follows:

$$\text{Intraregional: } a_{i,j}^{1,1} = \frac{z_{ij}^{1,1}}{x_j^1} \text{ where } A^{1,1} = \begin{bmatrix} a_{1,1}^{1,1} & a_{1,2}^{1,1} & \cdots & a_{1,n}^{1,1} \\ a_{1,1}^{1,1} & a_{2,2}^{1,1} & \cdots & a_{2,n}^{1,1} \\ \cdots & \cdots & \ddots & \vdots \\ a_{n,1}^{1,1} & a_{n,2}^{1,1} & \cdots & a_{n,n}^{1,1} \end{bmatrix}$$

$$\text{Interregional: } a_{i,j}^{1,10} = \frac{z_{i,j}^{1,10}}{x_j^{10}} \text{ where } A^{1,10} = \begin{bmatrix} a_{1,1}^{1,10} & a_{1,2}^{1,10} & \cdots & a_{1,n}^{1,10} \\ a_{1,1}^{1,10} & a_{2,2}^{1,10} & \cdots & a_{2,n}^{1,10} \\ \cdots & \cdots & \ddots & \vdots \\ a_{n,1}^{1,10} & a_{n,2}^{1,10} & \cdots & a_{n,n}^{1,10} \end{bmatrix}$$

Following the basic equation of IO analysis (I – A) · X = Y, where 'I' is the identity matrix, 'A' is the technical coefficients matrix, 'X' output and 'Y' the final demand, the inter-regional Leontief system for the IO model is [29]:

$$\left\{ \begin{bmatrix} I & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & I \end{bmatrix} \begin{bmatrix} A^{1,10} & \cdots & A^{1,10} \\ \vdots & \ddots & \vdots \\ A^{10,1} & \cdots & A^{10,10} \end{bmatrix} \right\} \begin{bmatrix} x^1 \\ \cdots \\ x^{10} \end{bmatrix} = \begin{bmatrix} Y^1 \\ \cdots \\ Y^{10} \end{bmatrix}$$

Table A.1
Overview of the 35 sectors represented in the IO model.

	Sector	Translation
1	Agricultura, silvicultura, exploração florestal	Agriculture and forestry
2	Pecuária e pesca	Livestock and fishing
3	Petróleo e gás natural	Oil and natural gas extraction
4	Mineração	Mining and quarrying
5	Alimentos e Bebidas	Food and beverage products
6	Têxteis, vestuário e calçados	Textiles, clothing and footwear products
7	Produtos de madeira - exclusive móveis	Wood products, excluding furniture
8	Celulose e produtos de papel	Pulp and paper products
9	Jornais, revistas, discos, móveis e indústrias diversas	Newspapers, magazines, records, furniture and other industries
10	Refino de petróleo e coque	Coke and refined petroleum products
11	Produtos químicos	Chemicals
12	Outros químicos	Other chemicals
13	Defensivos agrícolas	Pesticides
14	Artigos de borracha e plástico	Rubber and plastics
15	Produtos minerais não metálicos	Non-metallic products
16	Aço e metalurgia	Iron, steel and metallurgy
17	Máquinas e equipamentos, inclusive manutenção e reparos	Machinery and equipment, including maintenance
18	Produtos eletroeletrônicos	Electrical and electronic products
19	Automóveis, camionetas e utilitários	Light vehicles
20	Peças e acessórios para veículos automotores	Car parts
21	Caminhões, ônibus e equipamentos de transporte	Trucks, busses and other vehicles and parts
22	Produção e distribuição de eletricidade, gás, água, esgoto e limpeza urbana	Electricity, gas and water supply
23	Construção civil	Construction
24	Comércio	Wholesale and retail trade
25	Transporte, armazenagem e correio	Transport and post
26	Serviços de informação, alojamento e alimentação, serviços prestados às empresas	Telecommunication, accommodation and food services, business services
27	Intermediação financeira, seguros e previdência complementar e serviços relacionados, atividades imobiliárias e aluguéis	Finance and insurance, real estate activities
28	Serviços de manutenção e reparação	Maintenance and repair
29	Educação mercantil e saúde mercantil	Private education and health services
30	Serviços prestados às famílias e associativas; serviços domésticos	Private households with employed persons
31	Educação pública, saúde pública e administração pública e seguridade social	Public health, education, public administration and social security
32	Cana total	Total sugarcane
33	Etanol total	Total ethanol
34	Açúcar total	Total sugar
35	Eletricidade total	Total electricity

The original IO model consisted of 56 sectors per region. However, for reasons of operability, the less relevant sectors with high similarities are grouped together, resulting in a total of 35 sectors in the final model (see Table A.1).

The GDP, labour and import effects were determined by multiplying the total output per sector per region (X) by their respective coefficients (A). These coefficients were determined by dividing the total sectoral GDP, labour and imports (taken from the interregional IO matrix) by their respective output values [29]. The sectoral GDP accounts for the sum of the total net indirect taxes on domestic and imported intermediate consumption, labour remuneration, capital remuneration and direct taxes over this sector. To calculate the effect on the trade balance, the imports per scenario were deducted from the ethanol exports, which was determined in the MAGNET model (see Section 3.2.2).

Income classes

Table A.2 lists the income classes that were used in this research. The classes were based on the level of income, as a share of the of minimum wage. For example, the first class receives up to half of the minimum wage, whilst class 12 receives more than 20 times the minimum salary per month.

Table A.2
The twelve income classes in Brazil, expressed as share of the minimum wage.
Source: RAIS [75].

Income class	Wages as share of the minimum wage
1	< 0.50
2	0.51–1.00
3	1.01–1.50
4	1.51–2.00
5	2.01–3.00
6	3.01–4.00
7	4.01–5.00
8	5.01– 7.00
9	7.01–10.00
10	10.01–15.00
11	15.01–20.00
12	> 20.00

Basic Prices

See Table A.3.

Table A.3
Basic prices of the commodities used in this research.

Commodity	Basic price (USD_{2012})	
Ethanol (l)	0.58	
Sugar (ton)	442	
Sugarcane (ton)	16.2	The basic price of sugarcane was calculated using the national IO tables and agricultural production [62] of IBGE for 2008.
Electricity (kWh)	59.2	
Petrol (l)	0.61	The basic price was calculated from the output of the refining sector in 2008 from IBGE [62] and the consumption of national energy balance [90].
Paddy rice (t)	383	The basic price for each crop was calculated using IBGE data [62] for the production in physical and monetary terms in 2008. To align the crop categories from MAGNET with the IBGE data, we assumed *maize* (IBGE) to represent *coarse grains* (MAGNET); *soy* to represent *oilseeds*; *highland cotton* to represent *fibre crops*; *citrus fruits* to represent *fruits and vegetables* and for *other crops* we assumed a production weighted average of the other categories.
Wheat (t)	322	
Grains (t)	223	
Oilseeds (t)	393	
Horticultural products (t)	177	
Fibre crops (t)	651	
Other crops (t)	306	
Livestock (unit)	155	The production of cattle in monetary terms in Brazil was the sum of the sectors cattle and cow milk from the IBGE IO tables [69]. This was divided by the number of cattle in 2008 (IBGE) to get the basic price per unit of cattle. By combining this basic price with the yield and the livestock area, we calculated the production value of the livestock sector.

Overview of results

See Tables A.4–A.8

Table A.4
Overview of socioeconomic effects in Brazil in 2012.

	Piracicaba	Presidente Prudente	Rest of São Paulo	Rest of South East	South west Goiás	Rest of Goiás	Rest of Centre West	South	North	North East + mapito	Total
	Direct										
GDP (million USD_{2012})	162	272	5530	1333	151	664	770	855	77	911	10,727
Imports (million USD_{2012})	14	22	448	96	11	44	66	82	11	80	874
Labour (fte)	8157	18,066	265,107	70,441	12,643	52,810	76,046	57,449	11,275	151,345	723,340
	Indirect										
GDP (million USD_{2012})	52	24	3100	1315	15	176	220	553	86	611	6151
Imports (million USD_{2012})	9	2	839	186	1	21	24	155	19	130	1386
Labour (fte)	2144	1448	106,028	37,628	1022	10,212	12,167	22,165	5527	40,575	238,917
	Induced										
GDP (million USD_{2012})	8	12	618	−272	8	67	−54	−42	10	−155	200
Imports (million USD_{2012})	−2	1	−215	−57	0	−3	−8	−41	2	−49	−373
Labour (fte)	755	469	40,240	−7075	620	4613	−3373	−742	744	−10,856	25,395

Table A.5
Overview of socioeconomic effects in Brazil in in 2030 the *Reference* scenario.

	Piracicaba	Presidente Prudente	Rest of São Paulo	Rest of South East	South west Goiás	Rest of Goiás	Rest of Centre West	South	North	North East + mapito	Total
	Direct										
GDP (million USD$_{2012}$)	234	409	8105	1133	519	1228	1756	519	74	863	14,840
Imports (million USD$_{2012}$)	23	36	710	95	42	98	166	59	12	86	1327
Labour (fte)	13,332	32,301	437,075	64,554	46,559	105,997	199,613	31,276	9174	166,514	1106,394
	Indirect										
GDP (million USD$_{2012}$)	62	30	3662	1441	33	298	368	529	101	603	7125
Imports (million USD$_{2012}$)	11	2	1011	203	3	38	39	157	23	132	1620
Labour (fte)	2672	2055	129,539	38,654	2627	17,982	22,682	20,864	6145	40,218	283,437
	Induced										
GDP (million USD$_{2012}$)	31	25	1914	124	28	209	12	127	37	42	2549
Imports (million USD$_{2012}$)	2	2	119	7	1	9	0	12	8	0	160
Labour (fte)	1890	1316	94,851	5976	2316	13,939	676	6729	2639	4259	134,591

Table A.6
Overview of socioeconomic effects in Brazil in 2030 in the *2030 Ethanol* scenario.

	Piracicaba	Presidente Prudente	Rest of São Paulo	Rest of South East	South west Goiás	Rest of Goiás	Rest of Centre West	South	North	North East + mapito	Total
	Direct										
GDP (million USD$_{2012}$)	227	593	9023	1075	806	1438	2742	861	442	1437	18,645
Imports (million USD$_{2012}$)	18	42	626	71	49	87	226	96	41	106	1362
Labour (fte)	10,293	35,038	391,845	53,689	60,794	104,452	255,991	58,281	79,695	292,344	1342,421
	Indirect										
GDP (million USD$_{2012}$)	67	9	3854	1317	−374	88	391	650	111	684	6798
Imports (million USD$_{2012}$)	10	−10	989	203	−71	−11	18	187	27	154	1497
Labour (fte)	2742	−505	93,690	29,652	−79,875	−21,667	17,339	23,446	5622	34,893	105,337
	Induced										
GDP (million USD$_{2012}$)	21	27	1447	−24	9	161	−73	111	68	−44	1701
Imports (million USD$_{2012}$)	−1	2	−157	−28	0	6	−11	−16	9	−37	−234
Labour (fte)	1554	1164	81,787	953	362	10,626	−2323	12,740	9502	13,489	129,855

Table A.7
Overview of socioeconomic effects in Brazil in 2030 in the *Ethanol: 2G* scenario.

	Piracicaba	Presidente Prudente	Rest of São Paulo	Rest of South East	South west Goiás	Rest of Goiás	Rest of Centre West	South	North	North East + mapito	Total
	Direct										
GDP (million USD$_{2012}$)	446	759	14,621	2113	1000	2288	3097	941	155	1684	27,103
Imports (million USD$_{2012}$)	32	44	877	118	55	115	211	99	24	104	1679
Labour (fte)	26,152	55,463	826,044	128,582	71,022	146,975	268,171	48,470	14,698	213,827	1799,403
	Indirect										
GDP (million USD$_{2012}$)	74	34	4418	1881	51	339	383	667	46	683	8576
Imports (million USD$_{2012}$)	10	−1	1210	246	0	20	17	187	26	145	1859
Labour (fte)	3299	2224	163,353	52,006	4990	18,377	23,683	22,886	−11,463	29,265	308,619
	Induced										
GDP (million USD$_{2012}$)	44	35	2719	305	49	313	54	195	58	87	3859
Imports (million USD$_{2012}$)	3	2	198	25	3	13	4	26	13	7	294
Labour (fte)	2671	1804	134,816	13,310	4718	20,992	4433	9976	3900	6900	203,520

Table A.8
Overview of socioeconomic effects in Brazil in 2030 in the *Ethanol: High Yield* scenario.

	Piracicaba	Presidente Prudente	Rest of São Paulo	Rest of South East	South west Goiás	Rest of Goiás	Rest of Centre West	South	North	North East + mapito	Total
	Direct										
GDP (million USD_{2012})	321	752	12,095	3159	1029	1891	3894	2932	120	3724	29,917
Imports (million USD_{2012})	30	61	1022	228	77	141	394	396	20	283	2653
Labour (fte)	20,402	59,674	701,214	246,814	87,567	154,245	443,800	340,338	14,104	1130,026	3198,183
	Indirect										
GDP (million USD_{2012})	84	40	5083	2105	−52	−451	530	984	46	988	9358
Imports (million USD_{2012})	13	−1	1343	286	−17	−115	37	259	28	201	2033
Labour (fte)	3704	2741	170,274	58,075	−15,178	−139,573	32,510	43,009	−11,667	72,889	216,784
	Induced										
GDP (million USD_{2012})	48	44	3098	458	53	332	83	339	67	194	4718
Imports (million USD_{2012})	4	3	276	52	3	38	9	55	15	23	477
Labour (fte)	2957	2388	151,953	21,298	4571	21,089	8055	26,336	4784	36,277	279,708

References

[1] IEA. Energy security and climate change: assessing interactions. OECD Publishing; 2007. http://dx.doi.org/10.1787/9789264109940-en.

[2] International Energy Agency. Key World Energy Statistics; 2015.

[3] Chum H, Faaij A, Moreira J, Berndes G, Dhamija P, Dong H, et al. Bioenergy. In: Edenhofer O, Pichs-Madruga R, Sokona Y, Seyboth K, Matschoss P, Kadner S, editors. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2011. p. 209–332.

[4] IEA. Biofuels for Transport. Paris, France: OECD Publishing; 2011. http://dx.doi.org/10.1787/9789264287600-en.

[5] Van den Wall Bake J, Junginger M, Faaij APC, Poot T, Walter A. Explaining the experience curve: cost reductions of Brazilian ethanol from sugarcane. Biofuels Bioprod Bioref 2009;33:644–58. http://dx.doi.org/10.1016/j.biombioe.2008.10.006.

[6] Renewable Fuels Association. Pocket Guide to Ethanol 2016; 2016.

[7] UN Comtrade 2014. ⟨http://comtrade.un.org/data/⟩. [Accessed 27 May 2014].

[8] Ministério da Agricultura Pecuária e Abastecimento. Anuário Estatístico da Agroenergia 2014; 2014.

[9] Sorda G, Banse M, Kemfert C. An overview of biofuel policies across the world. Energy Policy 2010;38:6977–88. http://dx.doi.org/10.1016/j.enpol.2010.06.066.

[10] Walter A, Galdos MV, Scarpare FV, Leal MRLV, Seabra JEA, da Cunha MP, et al. Brazilian sugarcane ethanol: developments so far and challenges for the future. Wiley Interdiscip Rev: Energy Environ 2014;3:70–92. http://dx.doi.org/10.1002/wene.87.

[11] Goldemberg J, Coelho ST, Guardabassi P. The sustainability of ethanol production from sugarcane. Energy Policy 2008;36:2086–97. http://dx.doi.org/10.1016/j.enpol.2008.02.028.

[12] IBGE. Produção Agrícola Municipal; 2016. ⟨http://www.sidra.ibge.gov.br/bda/pesquisas/pam/default.asp?O = 29&i = P⟩. [Accessed 24 May 2016].

[13] Lapola DM, Schaldach R, Alcamo J, Bondeau A, Koch J, Koelking C, et al. Indirect land-use changes can overcome carbon savings from biofuels in Brazil. Proc Natl Acad Sci USA 2010;107:3388–93. http://dx.doi.org/10.1073/pnas.0907318107.

[14] Searchinger T, Heimlich R, Houghton RAR, Dong F, Elobeid A, Fabiosa J, et al. Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. (80). Science 2008;319:1238–40. http://dx.doi.org/10.1126/science.1151861.

[15] Fritsche UR, Sims REHH, Monti A. Direct and indirect land-use competition issues for energy crops and their sustainable production - an overview. Biofuels Bioprod Bioref 2010;4:692–704. http://dx.doi.org/10.1002/bbb.258.

[16] Wicke B, Verweij P, van Meijl H, van Vuuren DP, Faaij APC. Indirect land use change: review of existing models and strategies for mitigation. Biofuels 2012;3:87–100. http://dx.doi.org/10.4155/bfs.11.154.

[17] Walter A, Dolzan P, Quilodrán O, De Oliveira JG, Da Silva C, Piacente F, et al. Sustainability assessment of bio-ethanol production in Brazil considering land use change, GHG emissions and socio-economic aspects. Energy Policy 2011;39:5703–16. http://dx.doi.org/10.1016/j.enpol.2010.07.043.

[18] Gomes P, Malheiros T, Fernandes V, Sobral M, do Carmo Sobral C. Environmental indicators for sustainability: a strategic analysis for the sugarcane ethanol context in Brazil. Environ Technol 2016;37:16–27. http://dx.doi.org/10.1080/09593330.2015.1059490.

[19] Kates RW, Parris TM, Leiserowitz AA. What is sustainable development? Goals, indicators, and practice. Environment 2005;47:8–21. http://dx.doi.org/10.1080/00139157.2005.10524444.

[20] Lozano R. Envisioning sustainability three-dimensionally. J Clean Prod 2008;16:1838–46. http://dx.doi.org/10.1016/j.jclepro.2008.02.008.

[21] United Nations. Sustainable Development Goals; 2015. ⟨http://www.un.org/sustainabledevelopment/sustainable-development-goals/⟩. [Accessed 17 February 2017].

[22] Machado PG, Picoli MCA, Torres LJ, Oliveira JG, Walter A. The use of socioeconomic indicators to assess the impacts of sugarcane production in Brazil. Renew Sustain Energy Rev 2015;52:1519–26. http://dx.doi.org/10.1016/j.rser.2015.07.127.

[23] Domac J, Richards K, Risovic S. Socio-economic drivers in implementing bioenergy projects. Biomass Bioenergy 2005;28:97–106. http://dx.doi.org/10.1016/j.biombioe.2004.08.002.

[24] Moraes MAFD, Oliveira FCR, Diaz-Chavez RA. Socio-economic impacts of Brazilian sugarcane industry. Environ Dev 2015;16:31–43. http://dx.doi.org/10.1016/j.envdev.2015.06.010.

[25] Moraes MAFD de, Bacchi MRP, Caldarelli CE. Accelerated growth of the sugarcane, sugar, and ethanol sectors in Brazil (2000–2008): effects on municipal gross domestic product per capita in the south-central region. Biomass Bioenergy 2016;91:116–25. http://dx.doi.org/10.1016/j.biombioe.2016.05.004.

[26] Gilio L, Azanha Ferraz Dias de Moraes M. Sugarcane industry's socioeconomic impact in São Paulo, Brazil: A spatial dynamic panel approach. Energy Econ 2016;58:27–37. http://dx.doi.org/10.1016/j.eneco.2016.06.005.

[27] Wicke B, Smeets E, Tabeau A, Hilbert J, Faaij A. Macroeconomic impacts of bioenergy production on surplus agricultural land—A case study of Argentina. Renew Sustain Energy Rev 2009;13:2463–73. http://dx.doi.org/10.1016/j.rser.2009.05.010.

[28] van Eijck J, Romijn H, Balkema A, Faaij A. Global experience with jatropha cultivation for bioenergy: an assessment of socio-economic and environmental aspects. Renew Sustain Energy Rev 2014;32:869–89. http://dx.doi.org/10.1016/j.rser.2014.01.028.

[29] Miller RE, Blair PD. Input-Output Analysis: Foundations and Extensions. Second edition Cambridge, UK: Cambridge University Press; 2009.

[30] Martinelli LA, Garrett R, Ferraz S, Naylor R. Sugar and ethanol production as a rural development strategy in Brazil: Evidence from the state of São Paulo. Agric Syst 2011;104:419–28. http://dx.doi.org/10.1016/j.agsy.2011.01.006.

[31] Sawyer D. Climate change, biofuels and eco-social impacts in the Brazilian Amazon and Cerrado. Philos Trans R Soc Lond B Biol Sci 2008;363:1747–52. http://dx.doi.org/10.1098/rstb.2007.0030.

[32] Hall J, Matos S, Severino L, Beltrão N. Brazilian biofuels and social exclusion: established and concentrated ethanol versus emerging and dispersed biodiesel. J Clean Prod 2009;17:77–85. http://dx.doi.org/10.1016/j.jclepro.2009.01.003.

[33] World Bank. GINI index (World Bank estimate); 2015. ⟨http://data.worldbank.org/indicator/SI.POV.GINI⟩, [Accessed 10 December 2015].

[34] Mukhopadhyay K, Thomassin PJ. Macroeconomic effects of the ethanol biofuel sector in Canada. Biomass Bioenergy 2011;35:2822–38. http://dx.doi.org/10.1016/j.biombioe.2011.03.021.

[35] Silalertruksa T, Gheewala SH, Hünecke K, Fritsche UR. Biofuels and employment effects: implications for socio-economic development in Thailand. Biomass and Bioenergy 2012;46:409–18. http://dx.doi.org/10.1016/j.biombioe.2012.07.019.

[36] de Carvalho AL, Antunes CH, Freire F. Economic-energy-environment analysis of prospective sugarcane bioethanol production in Brazil. Appl Energy 2016;181:514–26. http://dx.doi.org/10.1016/j.apenergy.2016.07.122.

[37] Souza A, Watanabe MDB, Cavalett O, Ugaya CML, Bonomi A. Social life cycle assessment of first and second-generation ethanol production technologies in Brazil.

Int J Life Cycle Assess 2016. http://dx.doi.org/10.1007/s11367-016-1112-y.
[38] Swenson D, Input-Outrageous: The Economic Impacts of Modern Biofuels Production. Biennial Implan National Users Conference, Indianapolis, IN. June 8–10, 2006, p. 1–13.
[39] Van Dyne DL, Weber JA, Braschler CH. Macroeconomic effects of a community-based biodiesel production system. Bioresour Technol 1996;56:1–6. http://dx.doi.org/10.1016/0960-8524(95)00173-5.
[40] Low SA, Isserman AM. Ethanol and the local economy: industry trends, location factors, economic impacts, and risks. Econ Dev Q 2008;23:71–88. http://dx.doi.org/10.1177/0891242408329485.
[41] da Costa CC, Burnquist HL, Guilhoto JJM. Relations of the regional Brazilian cane agro-industry with the national economy: analysis applied to the Centre-South and North-Northeast. Appl Econ 2006;38:519–31. http://dx.doi.org/10.1080/00036840500391039.
[42] Burnquist HL, da Costa CC, Guilhoto JJM. Impacts of changes in regional sugar and ethanol exports upon Brazilian overall economy. 2004.
[43] Guilhoto JJM, Mendonça de Barros AL, Marjotta-Maistro MC, Istake M. Mechanization process of the sugar cane harvest and its direct and indirect impact over the employment in Brazil and in its 5 macro regions; 2002.
[44] Cunha MP Da, Scaramucci JA. Bioethanol as basis for regional development in Brazil: An input-output model with mixed technologies. In: Proceedings of the 46th Congr Eur Reg Sci Assoc (ERSA); 2006.
[45] M.A.F.D. de Moraes, da Costa CC, Guilhoto JJM, de Souza LGA, de Oliveira FCR. Social externalities of fuels. Ethanol Bioelectr Sugarcane Futur Energy Matrix 2010:44–75.
[46] Herreras Martínez S, van Eijck J, Pereira da Cunha M, Guilhoto JJM, Walter A, Faaij APCAA. Analysis of socio-economic impacts of sustainable sugarcane–ethanol production by means of inter-regional Input–Output analysis: demonstrated for Northeast Brazil. Renew Sustain Energy Rev 2013;28:290–316. http://dx.doi.org/10.1016/j.rser.2013.07.050.
[47] Compeán RG, Polenske KR. Antagonistic bioenergies: technological divergence of the ethanol industry in Brazil. Energy Policy 2011;39:6951–61. http://dx.doi.org/10.1016/j.enpol.2010.11.017.
[48] Woltjer G, Kuiper M, Kavallari A, van Meijl H, Powell J, Rutten M. et al. The Magnet Model - Module description. Wageningen, The Netherlands; 2014.
[49] Verstegen JA, Karssenberg D, van der Hilst F, Faaij A. Spatio-temporal uncertainty in Spatial Decision Support Systems: a case study of changing land availability for bioenergy crops in Mozambique. Comput Environ Urban Syst 2012;36:30–42. http://dx.doi.org/10.1016/j.compenvurbsys.2011.08.003.
[50] van der Hilst F, Verstegen JA, Woltjer G, Smeets EMW, Faaij APC, Mapping direct and indirect land use changes resulting from biofuel production and the effect of LUC mitigation measures. (Under review).
[51] Guilhoto JJM. Matrizes Interregionais de Insumo-Produto, Brasil (2008); 2010. ⟨http://www.usp.br/nereus/?Dados=matrizes-interregionais-de-insumo-produto-brasil-2008⟩. [Accessed 17 October 2016].
[52] Jonker JGG, van der Hilst F, Junginger HM, Cavalett O, Chagas MF, Faaij APC. Outlook for ethanol production costs in Brazil up to 2030, for different biomass crops and industrial technologies. Appl Energy 2015;147:593–610. http://dx.doi.org/10.1016/j.apenergy.2015.01.090.
[53] Sparovek G, Berndes G, Egeskog A, de Freitas FLM, Gustafsson S, Hansson J. Sugarcane ethanol production in Brazil: an expansion model sensitive to socio-economic and environmental concerns. Biofuels Bioprod Bioref 2007;1:270–82. http://dx.doi.org/10.1002/bbb.31.
[54] Rudorff BFT, de Aguiar DA, da Silva WF, Sugawara LM, Adami M, Moreira MA. Studies on the rapid expansion of sugarcane for ethanol production in São Paulo State (Brazil) using landsat data. Remote Sens 2010;2:1057–76. http://dx.doi.org/10.3390/rs2041057.
[55] Sparovek G, Berndes G, Paulo S, Egeskog A, de Freitas FLM, Gustafsson S, Hansson J. Sugarcane ethanol production in Brazil: an expansion model sensitive to socio-economic and environmental concerns. Biofuels Bioprod Bioref 2007;1:270–82. http://dx.doi.org/10.1002/bbb.31.
[56] Lehtonen M. Social sustainability of the Brazilian bioethanol: power relations in a centre-periphery perspective. Biomass Bioenergy 2011;35:2425–34. http://dx.doi.org/10.1016/j.biombioe.2009.05.027.
[57] IBGE. Divisão Territorial Brasileira; 2012. ⟨http://www.ibge.gov.br/home/geociencias/cartografia/default_dtb_int.shtm⟩ [Accessed 24 May 2013].
[58] IBGE. Produção Agrícola Municipal. Séries Históricas E Estatísticas; 2012. ⟨https://seriesestatisticas.ibge.gov.br⟩. [Accessed May 25, 2013].
[59] Estado de São Paulo. Lei Estadual N° 11.241, De 19 De Setembro De 2002; 2002. ⟨http://www.iea.sp.gov.br/out/bioenergia/legislacao/2002_lei_est_11241.pdf⟩. [Accessed 19 July 2016].
[60] UNICA, Estado de São Paulo. Protocolo agroambiental; 2011. ⟨http://www.ambiente.sp.gov.br/etanolverde/files/2011/10/diretivasTecnicasUsinas.pdf⟩. [Accessed 19 July 2016].
[61] de Freitas FLM, Sparovek G. Sugarcane expansion near to agrarian reform settlements: a case study of Pontal, Brazil. Int Arch Photogramm Remote Sens Spat Inf Sci 2008;37:89–94⟨http://www.isprs.org/proceedings/XXXVII/congress/8_pdf/1_WG-VIII-1/17.pdf⟩.
[62] IBGE. Banco de Dados Agregaods; 2016. ⟨http://www.sidra.ibge.gov.br/⟩.
[63] Jonker JGG, Junginger HM, Verstegen JA, Lin T, Rodríguez LF, Ting KC, et al. Supply chain optimization of sugarcane first generation and eucalyptus second generation ethanol production in Brazil. Appl Energy 2016;173:494–510. http://dx.doi.org/10.1016/j.apenergy.2016.04.069.
[64] IBGE. Área Geográfica publicada nos Censos. Censo Demográfico; 2013. ⟨http://www.ipeadata.gov.br/⟩. [Accessed 24 May 2016].
[65] IBGE. População residente; 2016. ⟨http://www.ipeadata.gov.br/⟩. [Accessed 24 May 2016].
[66] IBGE. População residente − 1° de julho - estimativas; 2014. ⟨http://www.ipeadata.gov.br/⟩. [Accessed 24 May 2016].
[67] IBGE. Produto Interno Bruto dos Municípios 1999–2013 2016. ⟨http://www.sidra.ibge.gov.br/bda/pesquisas/PIBMun/default.asp⟩ [Accessed 24 May 2016].
[68] IBGE. Pesquisa Pecuária Municipal; 2014. ⟨http://www.sidra.ibge.gov.br/bda/pesquisas/ppm/⟩. [Accessed 26 May 2016].
[69] IBGE. Sistema de Contas Nacionais; 2010. ⟨http://downloads.ibge.gov.br/downloads_estatisticas.htm⟩. [Accessed 30 September 2015].
[70] IBGE. Instituto Brasileiro de Geografia e Estatística; 2016. ⟨http://www.ibge.gov.br/home/⟩. [Accessed 17 October 2016].
[71] Guilhoto JJM, GonçalvesJr CA, Coelho Visentin J, Imori D, Ussami KA. Construção da Matriz Inter-regional de Insumo-produto para o Brasil: Uma aplicação do TUPI. São Paulo, Brasil; 2017.
[72] IBGE. Pesquisa Industrial Anual Produto; 2013. ⟨http://www.sidra.ibge.gov.br/bda/pesquisas/piaprod/⟩. [Accessed 24 May 2016].
[73] IBGE. Pesquisa anual de Serviços; 2013. ⟨http://www.sidra.ibge.gov.br/bda/pesquisas/pas/⟩. [Accessed 25 May 2016].
[74] da Cunha MP. Inserção do sector sucroalcooleiro na matriz energética do Brasil: uma análise de insumo-produto. UNICAMP; 2005.
[75] Ministério do Trabalho e Emprego. RAIS survey; 2008. ⟨http://acesso.mte.gov.br/portal-mte/rais/#2⟩. [Accessed 31 October 2016].
[76] UNICA. UNICA data; 2016. ⟨http://www.unicadata.com.br⟩. [Accessed 22 April 2016].
[77] Verstegen JA, van der Hilst F, Woltjer G, Karssenberg D, de Jong SM, Faaij APC. What can and can't we say about indirect land-use change in Brazil using an integrated economic - land-se change model? GCB Bioenergy 2015;8:561–78. http://dx.doi.org/10.1111/gcbb.12270.
[78] The European Parliament and The Council of The European Union. Renewable Energy Directive/28/EC. 2009; 2009.
[79] UNICA. Final report of 2013 / 2014 harvest season South-Central region; 2014.
[80] Gasques JG, Bastos ET, Valdes C. Preços da Terra no Brasil; 2008.
[81] Watanabe MDB, Chagas MF, Cavalett OO, Guilhoto JJM, Griffin WM, Cunha MP, et al. Hybrid input-output life cycle assessment of first- and second-generation ethanol production technologies in Brazil. J Ind Ecol 2016;20:764–74. http://dx.doi.org/10.1111/jiec.12325.
[82] sugarcane.org. Impact on Brazil's Economy; 2013. ⟨http://sugarcane.org/the-brazilian-experience/impact-on-brazils-economy⟩. [Accessed 18 May 2016].
[83] de Moraes MAFD. Sugarcane-bioethanol workforce in Brazil: employment, education, social inclusion; 2013. ⟨http://www.clacs.illinois.edu/lemann/documents/dialogue/MMoraes-Sugarcane-Ethanol⟩ Workforce in Brazil Employment, Education, Social Inclusion.pptx. [Accessed 18 May 2016].
[84] Machado PG, Walter A, Picoli MC, João CG. Potential impacts on local quality of life due to sugarcane expansion: a case study based on panel data analysis. Environ Dev Sustain 2016:1–24. http://dx.doi.org/10.1007/s10668-016-9823-6.
[85] Allan G. The regional economic impacts of biofuels: A review of multisectoral modelling techniques and evaluation of applications; 2011.
[86] Walter A, Gerber Machado P. Socio-Economic Impacts of Bioethanol from Sugarcane in Brazil. In: Rutz D, Janssen R, editors. Socio-economic Impacts of Bioenergy Production. Springer; 2014. p. 193–213.
[87] sugarcane.org. Worker Training & Job Assistance; 2011. ⟨http://sugarcane.org/sustainability/responsible-labor-conditions/worker-training-job-assistance⟩. [Accessed 18 May 2016].
[88] Dias MOS, Cunha MP, Jesus CDF, Rocha GJM, Pradella JGC, Rossell CEV, et al. Second generation ethanol in Brazil: can it compete with electricity production? Bioresour Technol 2011;102:8964–71. http://dx.doi.org/10.1016/j.biortech.2011.06.098.
[89] Dias MOS, Junqueira TL, Cavalett O, Cunha MP, Jesus CDF, Rossell CEV, et al. Integrated versus stand-alone second generation ethanol production from sugarcane bagasse and trash. Bioresour Technol 2012;103:152–61. http://dx.doi.org/10.1016/j.biortech.2011.09.120.
[90] Empresa de Pesquisa Energética. Balanço energético nacional. Rio de Janeiro; 2015. ⟨https://ben.epe.gov.br/downloads/Relatorio_Final_BEN_2015.pdf⟩. [Accessed 19 July 2016].