Renewable and Sustainable Energy Reviews 88 (2018) 347–362

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

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

Marnix L.J. Brinkman[a,*], Marcelo P. da Cunha[b], Sanne Heijnen[a], Birka Wicke[a], Joaquim J.M. Guilhoto[c,1], Arnaldo Walter[d], André P.C. Faaij[e], Floor van der Hilst[a]

[a] Copernicus Institute of Sustainable Development, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands
[b] Institute of Economics, University of Campinas, Rua Pitágoras 353, Campinas, Brazil
[c] Faculty of Economy, Administration and Accounting, University of São Paulo, Organization for Economic Co-operation and Development, Avenida Professor Luciano Gualberto 908, Butantã, Brazil
[d] Department of Energy, Faculty of Mechanical Engineering, University of Campinas, Rua Mendeleyev 200, Campinas, Brazil
[e] Energy and Sustainability Research Institute, University of Groningen, Nijenboismrgh 6, P.O. Box 221, 9700 AE Groningen, The Netherlands

ARTICLE INFO

Keywords:
Input-output analysis
GDP
Employment
Biofuel
Spatial distribution
Spill-over effects
Social impacts
Sustainability

ABSTRACT

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

* Corresponding author.
E-mail addresses: m.l.j.brinkman@uu.nl (M.L.J. Brinkman), marcelocunha@eco.unicamp.br (M.P. da Cunha), b.wicke@uu.nl (B. Wicke), joaquim.guilhoto@oecd.org (J.J.M. Guilhoto), awalter@fem.unicamp.br (A. Walter), a.p.c.faaij@rug.nl (A.P.C. Faaij), f.vanderhilst@uu.nl (F. van der Hilst).
[1] The contents of this publication express the views of Joaquim Guilhoto and does not necessarily represent the views of OECD or of its member countries.

https://doi.org/10.1016/j.rser.2018.02.014
Received 31 December 2016; Received in revised form 8 September 2017; Accepted 15 February 2018
Available online 22 March 2018

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%.