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Modeling and Analysis

Economic, environmental, and social impacts of different sugarcane production systems

Terezinha F. Cardoso, Marcos D.B. Watanabe, Alexandre Souza, Mateus F. Chagas, Otávio Cavalett, Edvaldo R. Morais, Luiz A.H. Nogueira, M. Regis L.V. Leal, Oscar A. Braunbeck, Luis A.B. Cortez, Antonio Bonomi

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Abstract

Mechanization in the sugarcane agriculture has increased over the last few years, especially in harvesting and planting operations, in the Brazilian Center-South region. The consequences of such a technological shift, however, are not fully comprehended when multiple perspectives are considered such as economic aspects, environmental regulations, and social context. The main goal of this study is to generate comprehensive information to subsidize decision-making processes not only in Brazil but also in other countries where sugarcane production is still under development. Manual and mechanical technologies for planting and harvesting were evaluated (with and without pre-harvest burning), as well as straw recovery, seeking to identify their advantages and disadvantages, considering economic, environmental, and social aspects. Considering vertically integrated production systems (agricultural and industrial phases), sugarcane production scenarios were compared under the metrics from engineering economics, life cycle assessment (LCA), and social LCA. Manual technologies were related to the highest job creation levels; however, lower internal rates of return and higher ethanol production costs were also observed. In general, mechanized scenarios were associated with lower ethanol production costs and higher internal rates of return due to lower biomass production cost, higher ethanol yield, and higher electricity surplus. Considering the restrictions for sugarcane burning and practical difficulties of manual harvesting of green cane, environmental analysis showed that mechanical harvesting of green cane with straw recovery presents, in general, the best comparative balance of environmental impacts. A multi-criteria decision analysis was performed to generate an output rank, confirming that mechanized scenarios presented the best sustainability performances. © 2017 Society of Chemical Industry and John Wiley & Sons, Ltd

2 Braunbeck OA and Magalhães PSG, Avaliação tecnológica da mecanização da cana-de-açúcar, in *BIOETANOL DE CANA-DE-AÇÚCAR: P&D Para Produtividade E Sustentabilidade*, ed by Cortez LAB. Blucher-FAPESP, São Paulo, pp 413–424 (2010).

3 União Da Indústria De Cana-De-Açúcar (UNICA), Apresentação da estimativa de safra 2013/2014. [Online]. Available at: **http://www.unica.com.br/documentos/apresentacoes/pag=2** [February 15, 2015].

4 Nunes Junior D, *Performance Indicators of Sugarcane Agroindustry: Seasons 2012/2013 and 2013/2014 (in Portuguese)*. Indicadores de desempenho da agroindústria canavieira. Grupo IDEA, Ribeirão Preto (2012).

5 Bordonal RO, Figueiredo EB, Aguiar DA, Adami M, Rudorff BFT and LA Scala N, Greenhouse gas mitigation potential from green harvested sugarcane scenarios in São Paulo State, Brazil. *Biomass Bioenerg* **59**: 195–207. (2013).

6 Figueiredo EB and LA Scala N, Greenhouse gas balance due to the conversion of sugarcane areas from burned to green harvest in Brazil. *Agric Ecosys Environ* **141:** 77–85. (2011).

7 Cerri CC, Feigl BJ, Galdos MV, Bernoux M and Cerri CEP, Estoques de carbono no solo e fluxo de gases do efeito estufa no agrossistema cana-de-açúcar, in *Bioetanol de Cana-de-Açúcar*. 1st ed., ed by . Blucher, São Paulo, p. 203–215 (2010)

8 Ribeiro BE, Beyond commonplace biofuels: Social aspects of ethanol. *Energy Pol* **57**: 355–362 (2013).

9 Moraes MAFD, Indicadores do mercado de trabalho do sistema agroindustrial da cana-de-açúcar do Brasil no período 1992–2005. *Estudos Econômicos. Instituto de Pesquisas Econômicas* **37:** 875–902 (2007).

12 Santos NB dos, Fernandes HC and Gadanha Jnr CD, Economic impact of sugarcane (Saccharum spp.) loss in mechanical harvesting. *Científica* **43:** 16–21 (2015).

13 Cavalett O, Cunha MP, Junqueira TL, Dias MOS, Jesus CDF, Mantelatto PE *et al.,* Environmental and economic assessment of bioethanol, sugar and bioelectricity production from sugarcane. *Chem Eng Trans* **25**: 1007–1012 (2011).

14 Cavalett O, Junqueira TL, Dias MOS, Jesus CDF, Mantelatto PE, Cunha MP *et al.,* Environmental and economic assessment of sugarcane first generation biorefineries in Brazil. *Clean Technol Environ Pol* **14**(3): 399–410 (2012).

15 Rodrigues EB and Saab OJGA, Avaliação técnico econômica da colheita manual e mecanizada da cana-de-açúcar (Saccharum spp.) na região de Bandeirantes-PR. Semina. *Ciências Agrárias* **28:** 581–588 (2008).

16 Silva FIC and Garcia A, Colheita mecânica e manual da cana-de-açúcar: histórico e análise. *Nucleus (Ituverava)* **6:** 204–217 (2009).

17 Bacchi MRP and Caldarelli CE, Impactos socioeconômicos da expansão do setor sucroenergético no Estado de São Paulo, entre 2005 e 2009. *Nova Economia* **25:** 209–224 (2015).

18 Capaz RS, Carvalho VSB and Nogueira LAH, Impact of mechanization and previous burning reduction on GHG emissions of sugarcane harvesting operations in Brazil. *Appl Energ* **102**: 220–228 (2013).

19 Martinez SH, Eijck JV, Cunha MP, Walter ACS, Guilhoto JJM and Faaij A, Analysis of socio-economic impacts of sustainable sugarcane-ethanol production by means of inter-regional input-output analysis: demonstrated for Northeast Brazil. *Renew Sustain Energ Rev* **28**: 290–316 (2013).

22 Bonomi A, Cavalett O, da Cunha MP, Lima MAP (Eds), *Virtual Biorefinery: An Optimization Strategy for Renewable Carbon Valorization*. Series: Green Energy and Technology, Springer International Publishing, Basel, Switzerland, 1st ed., XL, 285 p. DOI: 10.1007/978-3-319-26045-7 (2016).

23 Newnan DG, Eschenbach TG and Lavelle JP, *Engineering Economic Analysis*. Oxford University Press, New York (2004).

24 CGEE, Centro de Gestão e Estudos Estratégicos, Bioetanol combustível: uma oportunidade para o Brasil - Brasília, DF. [Online]. (2009). Available at: **http://www.cgee.org.br/publicacoes/bieotanol.php** [July 27, 2010].

25 CONAB: Perfil do Setor de Açúcar e Álcool no Brasil – Safra 2011/2012. Responsáveis técnicos: Ângelo Bressan Filho e Roberto Alves de Andrade. *Brasília* **5:** 1–88 (2013)

26 Hassuani SJ, Leal MRLV and IC Macedo (Eds), *Biomass Power Generation. Sugar Cane Bagasse and Trash*. UNDP-UN and Centro de Tecnologia Canavieira-CTC, Piracicaba, Brazil (2005).

27 Ripoli TCC and Ripoli MLC, *Biomassa de cana-de-açúcar: colheita, energia e ambiente*. Piracicaba: Escola Superior de Agricultura "Luiz de Queiroz" (2009).

28 Magalhães PSG, Nogueira LAH, Canatarella H, Rossetto R, Franco HCJ and Braunbeck OA, Agro-industrial technological paths. In *Sustainability of Sugarcane Bioenergy*, ed by MK Poppe and Cortez LAB. Center of Strategic Studies and Management (CGEE), Brasília, Brazil, p. 27–69 (2012)

29 Cardoso TF, Chagas MF, Rivera EC, Cavalett O, Morais ER, Geraldo VC, Braunbeck O *et al.,* A vertical integration simplified model for straw recovery as feedstock in sugarcane biorefineries. *Biomass Bioenerg* **81**: 216–223 (2015).

31 BV Raij, H Cantarella, JA Quaggio and AMC Furlani (Eds), *Recomendações de adubação e calagem para o Estado de São Paulo*. 2nd Ed. Boletim Técnico, 100, Campinas, IAC, 285 p. (1997).

32 Rossetto R, Dias FLF, Vitti AC, Cantarella H and Landell MGA, Manejo conservacionista e reciclagem de nutrientes na cana-de-açúcar tendo em vista a colheita mecânica. *Informações Agronômicas, Piracicaba*, **1:** 8–13 (2008).

33 Dias MOS, Modesto M, Ensinas AV, Nebra SA, Maciel Filho R, Rossell CEV, Improving bioethanol production from sugarcane: evaluation of distillation, thermal integration and cogeneration systems. *Energy* **36:** 3691–3703 (2011).

34 CEPEA, The CEPEA registers. [Online]. Center for Advanced Studies on Applied Economics (CEPEA) (2014). Available at: **http://www.cepea.esalq.usp.br** [July 10, 2014].

35 Government of Brazil, MME Energy auctions. [Online]. Ministry of Mines and Energy (MME) (2014). Available at: **http://www.mme.gov.br/programas/leiloes_de_energia/** [July 5, 2014].

36 ISO International Organization for Standardization, *Environmental management – Life Cycle assessment – Principles and framework – ISO 14.040*. ISO, Geneva (2006).

37 ISO International Organization for Standardization, *Environmental management - Life cycle assessment - Requirements and guidelines*. ISO 14044. ISO, Geneva (2006).

38 UNEP/SETAC, *Life Cycle Initiative. Guidelines for Social Life Cycle Assessment of Products*. United Nations Environment Programme, Paris, France (2009).

39 Macombe C and Loeillet D, Social life cycle assessment, for who and why? in *Social LCAs: Socio-economic*

41 MPS, Anuário Estatístico da Previdência Social – AEAT. [Online]. Ministério da Previdência Social (2015). Avaialble at: **http://www.previdencia.gov.br/estatisticas/**, (January 20, 2015).

42 IEA Instituto de Economia Agrícola. Banco de dados. [Online]. Available at: **http://www.iea.sp.gov.br/out/bancodedados.html** [March 25, 2015].

43 ANP Agência Nacional do Petróleo, Gás Natural e Biocombustíveis. Boletim Anual de Preços de Petróleo. [Online]. Gás Natural e Combustíveis nos Mercados Nacional e Internacional (2012). Available at: **www.anp.gov.br** [March 25, 2015].

44 Diakoulaki D, Mavrotas G and Papayannakis L, Determining objective weights in multiple criteria problems: The critic method. *Computers and Operations Research* **22**: 763–770 (1995).

45 Alemi-Ardakani M, Milani AS, Yannacopoulos S and Shokouhi G, On the effect of subjective, objective and combinative weighting in multiple criteria decision making: A case study on impact optimization of composites. *Expert Systems with Applications* **46:** 426–438. (2016).

46 Jahan A, Mustapha F, Sapuan SM, Ismail MY and Bahraminasab M, A framework for weighting of criteria in ranking stage of material selection process. *Int J Adv Manuf Technol* **58:** 411–420 (2012).

47 Brans JP, Vincke P and Mareschal B, How to select and how to rank projects: The Promethee method. *Eur J Op Res* **24:** 228–238 (1986)

48 Parajuli R, Knudsen MT and Dalgaard T, Multi-criteria assessment of yellow, green, and woody biomasses: Pre-screening of potential biomasses as feedstocks for biorefineries. *Biofuels Bioprod Bioref* **9:** 545–566 (2015).