Journal of Cleaner Production xxx (2016) 1–8

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Life cycle assessment for enhancing environmental sustainability of sugarcane biorefinery in Thailand

Thapat Silalertruksa [a, b], Patcharaporn Pongpat [a, b], Shabbir H. Gheewala [a, b, *]

[a] The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, 126 Prachauthit, Bangmod, Tungkru, Bangkok 10140, Thailand
[b] Center of Excellence on Energy Technology and Environment, PERDO, Bangkok, Thailand

ARTICLE INFO

Article history:
Received 30 November 2015
Received in revised form
23 May 2016
Accepted 1 June 2016
Available online xxx

Keywords:
Sugarcane
Biorefinery
Life cycle assessment
Thailand

ABSTRACT

Biorefinery concept is gaining interest as a promising option for enhancing the benefits of biomass in the sugarcane industry. The study assesses the environmental sustainability of sugarcane biorefinery systems expressed in terms of potential environmental impacts. The biorefinery system includes sugarcane cultivation and harvesting, sugarcane milling and by-product utilization i.e. bagasse for steam and electricity, molasses for ethanol, and vinasse for fertilizer and soil conditioner. The results revealed that the improvement of sugarcane cultivation and harvesting practice e.g. green cane production along with integrated utilization of biomass residues through the entire chain would help reduce the environmental impacts of the main products derived from sugarcane e.g. sugar and ethanol. The potential impacts on climate change, acidification, photo-oxidant formation, particulate matter formation and fossil depletion could be reduced by around 38%, 60%, 90%, 63% and 21%, respectively. Hotspots identified from the results of this LCA study can provide the important information for policy makers towards enhancing sustainable sugarcane production in the future. Recommendations for effective implementation of the proposed sugarcane biorefinery options to Thai sugarcane and sugar industries are discussed.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Sugarcane is an economic crop grown widely in the tropical and subtropical regions of the world. In 2014, it was estimated there were about 27 million hectares of sugarcane plantation areas, in more than 100 countries (FAOSTAT, 2015). Brazil is the largest sugarcane producer contributing about 39% of total world sugarcane production, followed by India (19%), China (7%), Thailand (5%), and Pakistan (4%) (FAOSTAT, 2015). So far, in the sugar mills, sugarcane is mainly utilized for its sucrose to be used as a sweetener. Bagasse, the biomass residue obtained after sucrose extraction, is used as fuel to provide steam and electricity to run the sugar mills. However, nowadays there is an increasing awareness that sugarcane and its co-products obtained from the processing system e.g. cane trash, bagasse, molasses, filter cake, etc. can be used for many applications by processing in a biorefinery to produce a wide range of products e.g. bioethanol, electricity as well as chemicals including a variety of polymers (Dias et al., 2013). The biorefinery concept is therefore gaining interest as a promising approach for enhancing competitiveness of the sugarcane industry which is recognized as a key agribusiness in many emerging economies including Thailand. Nevertheless, the implementation of biorefinery concept needs to be investigated using life cycle assessment to ensure the environmental sustainability of the industry development.

Thailand has a total sugarcane planted area of around 1.7 M ha and about 104 M ton of cane were produced in 2014 (OAE, 2014). The annual domestic consumption of sugar was only 2.5 M ton while the total sugar production was around 11 M ton. This surplus sugar production therefore led Thailand to be the 2nd largest sugar exporter. The sugarcane and sugar industry is therefore recognized as an important agro-industrial sector of the Thai economy. Selling and export of sugar products contributed about US$ 2462 million to the country's economy (OAE, 2014). The sugarcane plantation associates with more than 310,000 households, mainly small-scale growers living in the rural areas (OAE, 2014). Apart from producing sugar, the Thai sugarcane industry also plays an important role as a bioenergy supplier for Thailand because sugarcane has a high

* Corresponding author. The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, 126 Prachauthit, Bangmod, Tungkru, Bangkok 10140, Thailand.
E-mail address: shabbir_g@jgsee.kmutt.ac.th (S.H. Gheewala).

http://dx.doi.org/10.1016/j.jclepro.2016.06.010
0959-6526/© 2016 Elsevier Ltd. All rights reserved.

proportion of biomass both in the form of solid biomass and readily fermentable sugars that can be used for biofuels. Bagasse, one of the by-products of sugar milling, is mainly used for power generation due to the promotion of Independent Power Producers (IPP) and Small Power Producers (SPP) schemes (DEDE, 2012). Sugarcane molasses, another by-product from sugar milling, is the major feedstock for bioethanol production; about 60% of the 1 Ml bioethanol production per day in 2013 was from molasses. The Thai government has also launched the Alternative Energy Development Plan (AEDP) by setting a target that renewables will contribute 25% of the country's energy mix by 2021. Under the AEDP, different types of renewable energy sources are promoted including bioenergy such as electricity from biomass and transportation fuels like bioethanol from sugarcane molasses.

Although sugar and sugarcane bioenergy have now developed into a relatively mature industry in Thailand, there are several issues of concern on the environmental sustainability including cane trash burning, life-cycle greenhouse gas emissions of sugarcane based bioenergy and eutrophication impact potential from vinasse of molasses ethanol plant (Gheewala et al., 2011; Silalertruksa and Gheewala, 2009). Life cycle assessment (LCA) studies in Thailand have so far largely been limited on the specific impact categories of the specific product not the full LCA e.g. greenhouse gas (GHG) emissions of sugarcane and molasses ethanol compared to gasoline (Silalertruksa and Gheewala, 2011), energy balance and GHG emissions of electricity generated from bagasse and sugarcane residues (Jenjariyakosoln et al., 2014; Kiatkittipong et al., 2009), carbon footprint of sugar products (Yuttitham et al., 2011) and water deprivation potential of molasses ethanol production (Gheewala et al., 2013). Also, the studies so far are based on the traditional sugarcane production system whereas nowadays the sugarcane industry is trying to shift to more mechanization since farming to harvesting as well as increasing benefits from sugarcane biomass utilization. The production system that integrates biomass conversion processes to produce fuels, heat, electricity and value-added products from biomass, or so called “biorefinery”, is therefore gaining attraction for the Thai sugarcane industry nowadays e.g. the sugar-ethanol-electricity mills and the integrated 1st and 2nd generation ethanol production (Gheewala et al., 2011; Dias et al., 2013). With the concept that, if the waste is properly treated, the benefits of industries will be both the reduction of end-of-pipe treatment costs and also creation of value from waste utilization. Promotion of both appropriate farm management practices as well as the integrated utilization and management of by-products and wastes generated from the entire life cycle of sugarcane production system are essential to the future competitiveness of the sugarcane industry. The study thus aims to assess the environmental performance of different sugarcane biorefinery options in Thailand using LCA.

2. Methods

Life cycle assessment (LCA) has been used in the study to quantify the potential environmental impacts of different sugarcane biorefinery options. The “ReCiPe” method, one of the life cycle impact assessment (LCIA) methods that recently developed by harmonizing two LCIA methods i.e. CML 2001 and Ecoindicator 99 (Goedkoop et al., 2008), has been referred in this study because it consists of a variety of impacts categories which will help policy decision makers ensure that all the potential impacts associated with the different sugarcane biorefinery options will be taken into account along with the trade-offs. The method is used to convert the consumed resources and emissions occurring over the sugarcane biorefinery system into the environmental impact indicators. Nine impact categories have been analysed include climate change, terrestrial acidification, freshwater eutrophication, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial ecotoxicity, freshwater ecotoxicity and fossil depletion.

The functional units of the studied sugarcane biorefinery systems are set for the four final products that will be obtained from the biorefinery i.e. 1 tonne of raw sugar, 1 tonne of refined sugar, 1000 L of molasses and 1 MWh of electricity. However, the reference unit as “per tonne cane processed” is the reference unit that is to explain how the outputs will be generated under the different biorefinery options. This is because the tonne cane processed is the preferred reference unit for the sugarcane industry sector for measuring the performance of their sugarcane production systems.

2.1. Sugarcane biorefinery systems

The system boundary of the sugarcane biorefinery (sugar-power-ethanol production) includes sugarcane cultivation and harvesting, transport of sugarcane, sugar milling, steam and power generation from bagasse, molasses ethanol production, and by-product utilization. The assessment also includes the environmental burdens from the production of chemicals and fuels that were used in the sugarcane biorefinery system. The description of the studied sugarcane biorefinery or namely “base case” and the three options for improving the environmental competitiveness of the sugarcane biorefinery are as follows:

2.1.1. Sugarcane biorefinery (base case)

The base case sugarcane biorefinery system represents the conventional farming practices with cane trash burning before harvesting, sugar milling, molasses ethanol production and steam and power generation from bagasse. Detailed information of the studied sugarcane biorefinery system is as follows:

(1) Sugarcane cultivation and harvesting

Conventional sugarcane farming data are primarily collected from field survey in central Thailand. The average sugarcane yield is 75 ton/ha-y. The input chemical fertilizers include ammonium sulfate, phosphate fertilizer, potassium chloride and urea at about 88, 88, 225 and 71 kg/ha-y, respectively. Agrochemicals used includes glyphosate, paraquat and atrazine at about 8, 5 and 6 kg/ha-y, respectively. The total diesel consumption for conventional farming is around 117 L/ha-y. This amount of fuel is mainly used for tractor during land preparation including subsoiling, 1st and 2nd ploughing. Manual planting is referred as the common practice for the base case. In the study, the 100% burnt cane during harvesting is used for base case scenario because it is the common practice of Thai sugarcane farmers. The statistics show that although mechanical harvesting is being promoted, the burnt cane still shares about 68% of the total cane processed in Thailand (OCSB, 2014). In addition, the assessment aims to compare this base case farming practice with mechanized farming with green cane harvesting being promoted by the sugarcane industry.

(2) Sugar milling

Sugarcane is delivered to the mill by truck and then loaded into the reception unit for washing and crushing to extract cane juice. At this stage, bagasse is separated and supplied to the steam and power plant. The cane juice is then passed through the clarification process to remove the impurities and concentrated into syrup. The obtained syrup is seeded with raw sugar crystals in a vacuum pan and boiled to get the crystals which are separated by centrifugation. From this step, molasses, the syrup remaining after the sugar has passed through the centrifuge for the last time in a mill, will be

Download English Version:

https://daneshyari.com/en/article/5481562

Download Persian Version:

https://daneshyari.com/article/5481562

Daneshyari.com