Energy and Greenhouse Gas Emissions Reduction Potential of Sugarcane Field Residues Power Generation in Thailand

S. Jenjariyakosoln, B. Sajjakulnukit, and S. Garivait

***Abstract*—This paper presents an approach to evaluate the net energy potential of sugarcane field residues in Thailand. It was estimated that around 13,595 ktons of sugarcane field residues was burned in the field annually in the country. Assuming 100% collection efficiency, this amount could be converted to 210.46 PJ through power generation. The quantity of greenhouse gases (GHGs) including CO_2, CH_4, and N_2O emitted from open burning of sugarcane residues was compared to that released from power production using life cycle analysis methodology for the estimation. It was found that the avoided GHG emissions obtained for power generation represent 11,836 ktons CO_2equivalent, based on the country specific emission factor of electricity production using coal as fuel of 1.09 kg CO_2/kWh. Although this enormous potential for energy production in Thailand, sugarcane field residues availability is subject to seasonal variability, which limits its capacity to serve as fuel for power generation. The total avoided GHG emissions were therefore 11,836 ktons CO_2eq and 8,285 ktons CO_2eq annually for collection efficiency of 100% and 70%, respectively. Comparatively to the national CO_2 emissions from coal power generation of 34,532 ktons CO_2eq in 2011, the avoided GHG emissions would be about 34% and 24% for collection efficiency of 100% and 70%, respectively.**

***Index Terms*—Greenhouse gas (GHG), sugarcane field residues, power generation, open burning, emission reduction.**

I. Introduction

Biomass is an abundant resource in Thailand, which can be utilized as fuel for power generation. Biomass fuel provides not only clean energy because of neutral emission of carbon dioxide (CO_2), and of high potential to substitute fossil fuels to meet energy demands of the country [1]-[2]. Electricity production is one of the major sectors of GHG emissions in Thailand. The national fossil fuel share for power generation is composed of 65.1% natural gas and 26.4% coal and lignite in the year 2011 [3].

A Renewable and Alternative Energy Development Plan for the period of 2012-2021 (AEDP 2012-2021) has been established by the Thai government in order to prevent energy shortage that the country may face, consisting in bringing the renewable and alternative energy share to 25% in 10 years [4]. In this plan, biomass for power generation will increase from currently 1,752 MW to 3,630 MW, i.e. 100% augmentation.

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Sugarcane field residues including sugarcane top and leaves are targeted to be the main biomass feedstock to achieve the AEDP 2012-2021, because of their abundance [5]. However, during the last decade about 60% of 18.26 Mt of the annual average sugarcane field residues, which represent about 18 Mt underwent field open burning in order to facilitate the sugarcane harvesting [6]. Treating sugarcane field residues as energy source rather than a waste can reduce the open field burning problem, avoid GHG emissions, and reduce energy imports.

In this study, we evaluated the potential of the current sugarcane field residues available amount for power generation and the associated GHG emission reduction with electricity production using coal as reference case. The methodology for estimating the amount of generated sugarcane field residues, their net amount available for energy production, their corresponding power potential, and the associated GHG emissions, was first presented. Then, the obtained results were described and discussed.

II. Methodology

A. Amount of Generated Sugarcane Field Residues

The amount of generated sugarcane field residues was estimated using the residue to product ratio (RPR) [8]. The RPR values are influenced by plant structure, seasonality, harvesting methods, irrigation practices, soil quality, moisture content, and various other minor factors [8]-[9]. The use of RPR for estimating the generated sugarcane field residues was opted in this study because it tolerated the calculation of the amount of residues in multi-cropping system like sugarcane plantation [9]. The RPR values of sugarcane field residues specific to Thailand were documented in different studies. They ranged between 0.23 and 0.30, with moisture content ranging from 10 up to 59% [10]-[13]. In this study, the average value of 0.28 was used for estimating the generated sugarcane field residues.

B. Net Availability of Sugarcane Field Residues

The net availability of sugarcane field residues for any further utilizations including for energy purposes was estimated based on the current unused amount. In Thailand, the actual use of sugarcane field residues is composed of (1) their incorporating into the soil, and (2) left in the field as organic fertilizer and weed control [5], [13]. On the other hand, a significant large amount of sugarcane field residues was open burned in the field, which could be considered as unused amount. The amount of open burned sugarcane field

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residues was calculated from the amount of burned sugarcanes divided by the annual total amount of sugarcane production. In this study, the data required for the calculations were obtained from Office of The Cane and Sugar Board (OCSB) for the period of 2002-2012 [6].

C. Power Potential of Sugarcane Field Residues

The net availability of sugarcane field residues representing the amount of biomass that could be used for power generation, the corresponding annual power generation was calculated using Equation (1).

$$\textit{Electricity output} = \textit{Sugarcane field residues} \times \textit{lower heating value} \times \textit{efficiency} \quad (1)$$

where Electricity output (MW) is the annual capacity of power production, sugarcane field residues (ton/year) are the net availability of annual sugarcane field residues, lower heating value (MJ/kg) is the lower heating value of sugarcane field residues, efficiency (%) is the electrical efficiency of power generation.

D. Estimation of Avoided GHG Emissions

Assuming the amount of power generation using sugarcane field residues as fuel would replace the grid electricity generated from coal power plants, the avoided GHG emissions could be estimated. For coal power plants GHG emissions, the country specific emission factors were used in this study. The GHG emissions from open burning of sugarcane field residues were estimated using the IPCC 2006 Guidelines method. Estimation of GHG emissions from open burning of sugarcane field residues

Based on the IPCC 2006 Guidelines for National Greenhouse Gas Inventories, the emission from open burning of sugarcane field residues was estimated using Equation (2) as follows.

$$E_i = A \times BD \times CF \times EF_i \times 10^{-6} \quad (2)$$

where E_i (ton of each pollutants) is the amount of the emitted GHG i from burning, A (ha) is the amount of burned area, BD (kg/ha) is mass of sugarcane field residues available for combustion, CF (dimensionless) is the combustion factor, and EF (g/kg) is emission factor of the GHG i [14].

From the Equation (2), the result of the multiplication of burned area, by mass of sugarcane field residues available for combustion, and by combustion factor represents the amount of sugarcane field residues burned.

E. Estimation of Life Cycle GHG Emissions from Power Generation Using Sugarcane Field Residues as Fuel

Using life cycle analysis methodology to assess the GHG emissions associated with all steps of the pathway of power generation using sugarcane field residues as fuel. This comprised (1) residues collection, (2) transportation of residues from field to power plant, and (3) pretreatment to prepare residues to be as feedstock (4) process of power generation. The emissions of CO_2, CH_4 and N_2O were estimated for all the steps included in the pathway using IPCC 2006 Guidelines, which can be summarized as follows.

$$E_i = \textit{Fuel consumption} \times EF_i \times 10^{-3} \quad (3)$$

where E_i (ton of GHG i) is the amount of emissions from the considered step activity, Fuel consumption (TJ) is the amount of fossil fuel combusted in the considered activity, and EF (kg/TJ) is the emission factor of the GHG i [14]-[15].

In this study, the base case was formulated based on a 40 MW advanced bagasse power plant operating conditions GHG emissions from the collection of sugarcane field residues were estimated using the diesel consumption of the used motorized baler per ton of residues [16]. As the baled residues was delivered to the power plant using 10-wheels diesel trucks with 4.4 tons per truckload in average [12], and about 100 km round trip distance from fields to the plant [17]. The loss of residues during the collection, transportation and pretreatment processes was assumed to be at most 5% based on the study [18]. Emissions from shredding of residues for feeding into the boiler was estimated from the electricity consumption per ton of residues [16], and the country specific emission factor of electricity production for Thailand in the year 2011 [19]. Emissions from power production using sugarcane field residues as fuel were calculated from the sugarcane field residues used as feedstock and 150 L per year of diesel oil for 1 MW capacity used for plant start-up and supplementary fuel [17].

III. Result and Discussions

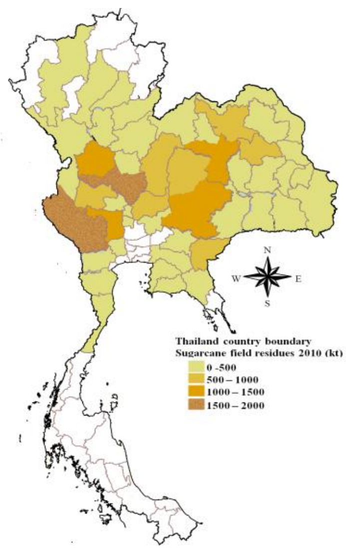
The national agricultural statistic data on sugarcane plantations and production were obtained from Office of Agricultural Economics (OAE) [20].

A. Annual Sugarcane Field Residues Generation

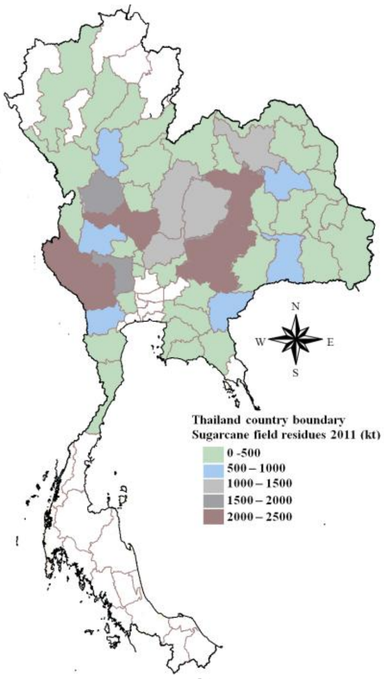
Fig. 1 represented the maps of sugarcane field residues generated for the year 2010-2012. The production of sugarcane field residues was represented in ktons per year.

The production of sugarcane field residues shown in Fig. 1 was comparatively high in the central and northeastern part of Thailand. It could be concluded from Fig. 1 that the annual amount in year 2011-2012 was rather significantly higher than year 2010. Besides, the annual variation of sugarcane field residues was not significant between 2011 and 2012.

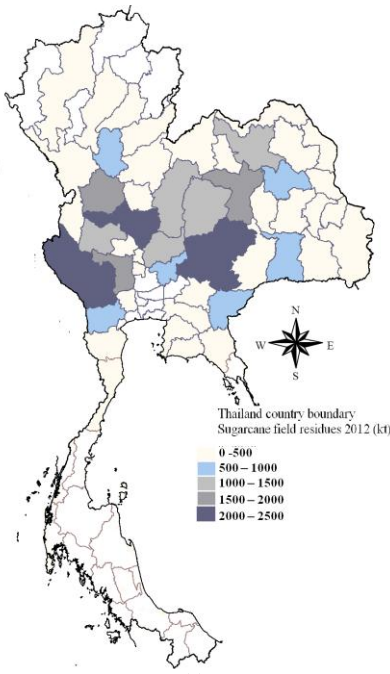
Table I show the five-years average (2008-2012) top ten provinces of sugarcane field residues production in Thailand [7].



(a)



(b)



(c)

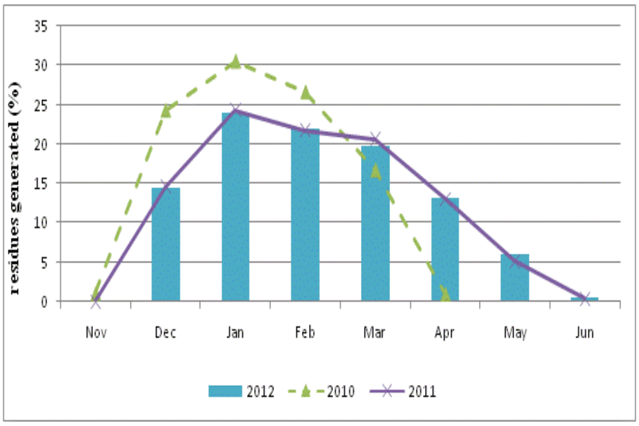
Fig. 1. Annual production and spatial distribution of sugarcane field residues in Thailand in (a) 2010, (b) 2011, (c) 2012.

TABLE I: THE TOP TEN PROVINCES OF SUGARCANE FIELD RESIDUES GENERATED IN THAILAND

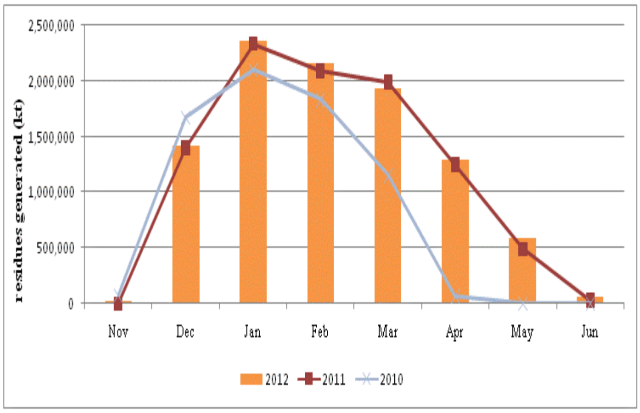
No	Province	Average over the past 5 years (ktons)
1	Nakhonsawan	2,029
2	Ratchaburi	1,528
3	Kamphaengphet	1,464
4	Chaiyaphum	1,429
5	Saraburi	1,311
6	Nakhonratchasima	1,289
7	Khon Kaen	1,108
8	Udonthani	1,083
9	Angthong	1,011
10	Kanchanaburi	0,952

B. Seasonal Variation and Spatial Distribution of Sugarcane Field Residues

Fig. 2 represents the monthly variation of generated sugarcane field residues in 2010- 2012.



(a)



(b)

Fig. 2. Monthly variation of sugarcane field residues generated in Thailand in 2010 – 2012 (a) Percentage of monthly generated sugarcane residues (b) Quantity of monthly generated sugarcane field residues

From Fig. 2 it could be observed that the monthly production of sugarcane field residues was not significantly different between 2011 and 2012. The pattern of monthly distribution of sugarcane harvested time in year 2011 and 2012 were longer than the year 2010. The sugarcane field residues were actually available during five months annually, in 2010-2012, it was from December to April.

From Fig. 1 and Fig. 2, it resulted that the total generated sugarcane field residues amounted about 22.66 Mtons annually in Thailand. Using the average amount of burned sugarcane divided by the total sugarcane production, it was found that about 60% of generated sugarcane field residues were subject to open burning, and consequently could be used for energy purposes.

C. Power Generation Potential of Available Sugarcane Field Residues

To estimate the power generation potential of available sugarcane field residues, the low heating value (LHV) of 15.48 MJ/kg determined by Energy for Environment Foundation [21] was used. The obtained potential was about 210 PJ annually. As sugarcane field residues can be used as fuel in the same technology type boilers as bagasse, we assumed in this study that the overall efficiency of the power plant was 20%, i.e. the efficiency of an advanced bagasse power plant [22]. This resulted in a theoretical power generation potential of 11,107 GWh annually, i.e. in case of 100% efficiency of residues collection. In case of a collection efficiency of 70%, which could be obtained when using current motorized balers in Thailand for the collection [23], the annual electricity generation potential would be about 7,775 GWh. Assuming an annual operating time of 24 h per day for at least 330 days per year [17], the total power capacity of sugarcane field residues would be 1,402 MW and 982 MW at 100% and 70% collection efficiency, respectively.

D. Avoided GHG Emissions

From the two scenarios, i.e. 100% and 70% collection efficiency, we could estimate the associate GHG emissions reduction. To this end, it was assumed that the generated from sugarcane field residues would substitute coal for the grid electricity production. The country specific emission factor (EF) of coal fired power plant was 1.09 tCO_2/MWh in year 2011 [19].

1) GHG emissions of electricity generation from sugarcane field residues

The life cycle assessment of the emissions of GHG including N_2O and CH_4 emissions from power generation process and CO_2 emissions from combustion of fossil fuels used in the collection, transportation and shredding of the residues. This resulted in emissions of 977 ktons CO_2eq and 684 ktons CO_2eq for collection efficiency of 100% and 70%, respectively.

2) GHG emissions from sugarcane field residues open burning

In Thailand, the open burning of sugarcane fields before harvest is a common practice to facilitate manual harvesting. Based on the sugarcane field residues availability for 100% and 70% collection efficiency scenarios, and a combustion factor of sugarcane field burning of 39% [24], GHG emissions from open burning of sugarcane field residues were 7,063 ktons CO_2eq and 4,944 ktons CO_2eq for collection efficiency of 100% and 70%, respectively.

The total avoided GHG emissions were therefore 11,836 ktons CO_2eq and 8,285 ktons CO_2eq annually for collection efficiency of 100% and 70%, respectively. Comparatively to the national CO_2 emissions from coal power generation of 34,532 ktons CO_2eq in 2011, the avoided GHG emissions would be about 34% and 24% for collection efficiency of 100% and 70%, respectively. Although the CO_2 emission from coal preparation for feedstock at coal power plant was excluded, the amount of CO_2 emission from coal power plants were greater than the GHG emissions from power generation using sugarcane field residues as fuel for approximately 35 times. However, the specific power plant that operates on sugarcane field residues alone is not available.

IV. Conclusion

The net amount of sugarcane field residues available for energy purposes was sufficiently high to be proposed as a substitute to coal for power generation. For the target of biomass power of the AEDP 2012-2021, the electricity generated from sugarcane field residues as fuel could be about 39% and 27% for collection efficiency of 100% and 70%, respectively. In addition, the energy use of sugarcane field residues provided a large mitigation of GHG emissions from fossil fuels and sugarcane field open burning. However, it was found that sugarcane field residues are available only during December-April in 2010-2012, i.e. 5 months of the year. In order to supply the power plant with the sugarcane residues the whole year-round, a fuel management system enabling to do so should be set. In addition, the techniques of biomass supply chain management for economical price of field residues using as fuel in power plant and for minimum negative impacts on environment and social are still developed. On the other hand, huge amount of sugarcane field residues were continuously subject to burning to facilitate the manual harvesting. For the sugarcane field residues use on sustainability, the development of governmental policy measures to motivate electricity producers to use sugarcane field residues should be realized.

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