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Energy and GHG emission reduction potential of power generation from sugarcane residues in Thailand

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ABSTRACT

Electric power production using biomass residues from agricultural production using high efficiency electricity generation technologies would reduce greenhouse gas (GHG) emissions and contribute to climate change mitigation. This study investigated the case of the sugar industry in Thailand and identified scenarios offering GHG emissions reduction benefits. Electricity generation potential from using sugarcane residues and/or upgrading power generation systems represent beneficial options. The largest potential of electricity export to the national grid can be achieved by upgrading boiler systems of all sugar mills to 103 bar and 515 °C. Using 19% of the generated sugarcane tops and leaves along with bagasse can generate 9 TWh electricity and would reduce GHG emissions by 4.8 Mt CO_2 equivalent a year. The economic analysis shows that using high steam pressure boiler configurations for power generation results in substantial reduction in production cost and increase in benefit.

Introduction

Renewable energy technologies have an important role in mitigating climate change through reduced anthropogenic greenhouse gas (GHG) emissions (IEA, 2011). Among the various renewable energy sources, biomass is currently gaining considerable interest among energy policy makers (Bakos et al., 2008; WEC, 2013). Agricultural residues, especially agro-industrial wastes, are widely used as fuel for power generation. Due to the increase in power demand and saturation of agro-waste utilization for power generation, the increase in electricity efficiency along with the utilization of field residues are receiving increased interest from researchers and policy makers (Bocci et al., 2009; Deepchand 2001; Guzman and Valdes, 2000; Hassuani et al., 2005; Khatiwada et al., 2012; Larson et al., 2001; Macedo et al., 2001; UNFCCC, 2014). In Thailand, electricity generation, being highly dependent on fossil fuels (67% natural gas, and 20% coal and lignite), is one of the major sectors contributing to GHG emissions (EPPO, 2012). Thailand formulated the Power Development Plan (PDP) for the period of 2010–2030 for energy security and adequacy by considering environment concerns, energy efficiency, and renewable energy. Promotion of both renewable energy and nuclear power was initially considered in this plan. However, following Japan's Fukushima incident in 2011, the revised plan in 2012 promoted natural gas cogeneration systems in the initial phase considering the existing infrastructure and domestic resources. This was planned to replace the older gas-fired stations by combined cycle power plants (US.EIA, 2013). Thailand is an agricultural country, so biomass sources especially agro-industrial wastes have been used as fuel for generating electricity for exporting to the national grid through the Small Power Producers (SPP) (10–90 MW) and Very Small Power Producers (VSPP) (<10 MW) schemes. Some of the supporting schemes and incentives for SPP and VSPP are the feed-in premium tariff, exemption of investment tax scheme, soft loans for renewable energy, and fund provisions for renewable energy investments (Asawachintachit, 2012; Sutabutr, 2010). An Alternative Energy Development Plan for 2012–2021 (AEDP 2012–2021) was also established by the Thai government to target increasing the share of renewable and alternative energy to 25% of total energy demand within 10 years, particularly increasing biomass power generation to 14,008 GWh, and reducing GHG emissions by 76 Mt CO_2 equivalent (CO_2e) annually (DEDE, 2012).

Increased power generation from agro-waste e.g. woodchips, rice husk, and bagasse has recently been achieved by upgrading technologies to increase electric efficiency. Many researchers have considered the feasibility of improving electric efficiency by upgrading technologies and using additional fuel to meet the increased feedstock demand. The surplus electricity production from sugarcane residues (bagasse combined with tops and leaves) with increasing efficiency by upgrading

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power generation technologies has successfully been developed in several countries e.g. Brazil, Cuba, India, Mauritius, and Thailand (Bocci et al., 2009; Deepchand 2001; Guzman and Valdes, 2000; Hassuani et al., 2005; Khatiwada et al., 2012; Larson et al., 2001; Macedo et al., 2001; UNFCCC, 2014). Especially, the cogeneration systems of sugar mills in Brazil had been developed from 22 bar boiler with back pressure turbines to 105 bar with extraction condensing steam turbine and using tops and leaves as additional fuel that increased surplus electricity export 16 folds (Khatiwada et al., 2012).

Thailand is the world's fourth largest sugar producer, producing 98 Mt and 10.43 Mt of sugarcane and sugar in 2012 respectively. Also, sugarcane production has been increasing 10% annually for the last 5 years (OAE, 2012; OCSM, 2013). The waste from sugarcane processing i.e. bagasse, is already being used as the main fuel for heat and power generation for sugar production with excess electricity being sold to the national grid (Mendoza et al., 2002; OCSB, 2007b). The amount of bagasse varies from 23% to 37% of the sugarcane (Deepchand, 2002), with an average of 28% (Larson et al., 2001; PDTI, 2011). Another residue that is interesting is the field residue from sugarcane cultivation i.e. tops and leaves which varies between 17 and 30% of the sugarcane (DEDE, 2005; DEDP, 1992; Junginger et al., 2001; KMUTT, 2006). The available amount of tops and leaves is approximately 74–98% of the total amount generated, the rest being left in the field for incorporation into the soil as organic fertilizer and weed control (DEDE, 2005; KMUTT, 2006; Sajjakulnukit et al., 2005). Most of the tops and leaves are currently open burnt in the field in order to facilitate sugarcane pre-harvesting, and post-harvesting for land preparation (KMUTT, 2006; Yuttitham et al., 2011). Utilizing tops and leaves as fuel for heat and power generation can help alleviate the open field burning problem, avoid GHG emissions and contribute to reducing energy imports (Bocci et al., 2009; DEDE, 2005, Gheewala et al., 2011; Guzman and Valdes, 2000; Mendoza et al., 2002). The tops and leaves can be used as a secondary fuel combined with bagasse in existing boilers, thereby avoiding the need for storing excessive amounts of tops and leaves which would be required if they are used as the primary fuel for the whole year operation due to their seasonal availability limited to 4–6 months annually in the harvesting season (Guzman and Valdes, 2000; OCSM, 2013). However, the cost of the supply chain process, including baling, field hauling and loading, truck transport, shredding and storage stacking, of the low bulk density tops and leaves is a major obstacle. Therefore this cost should be factored in considerations for using this residue.

Currently, most sugar mills in Thailand operate low efficiency grate boilers and back pressure steam turbines with steam pressure about 20 bar and temperature 350–360 °C; the plants produce energy for their own needs (sugar milling) for the most part with only some excess electricity being exported to the national grid (PDTI, 2011). The average electricity export is only 14.5 kWh/ton sugarcane (tc) as compared to 70 kWh/tc and 158 kWh/tc that have been observed for the most advanced sugar mills in Thailand and Brazil respectively (Khatiwada et al., 2012; Siemers, 2010). For new units recently equipped in the more advanced sugar mills in Thailand with boilers that produce steam at 103 bar and 515 °C, high amount of surplus electricity can be produced for export to the grid; but additional fuel is required which can possibly be provided by tops and leaves (ONEP, 2013). Siemers (2010) evaluated the increasing surplus electricity generation and GHG reduction using the best available boiler technology in Thailand. However, this study was based on the existing technology in 2006 at the highest boiler steam pressure of 70 bar and considering either bagasse or tops and leaves as feedstock, but not a combination of both. Hence, a need was perceived for updating the study with more current technology (103 bar boiler pressure), using both residues (bagasse as well as tops and leaves) in combination accounting for actual demand and availability, and considering actual data via extensive site surveys.

The study aims to evaluate the electricity generated from sugarcane residues (tops and leaves, and bagasse) by upgrading the boiler configurations in the existing power plants with high pressure steam turbines. The associated GHG emissions from increasing surplus electricity are evaluated and compared to natural gas combined cycle power plants that are expected to be constructed following the Thailand PDP 2010 plan, and be the marginal power plants displaced by the surplus electricity. The electricity export potential of different production systems is also evaluated in terms of economic analysis to encourage sugar mill owners or investors to consider exporting more electricity. The cost models used are general and can be also applied to other biomass feedstocks and locations.

Methodology

The methodology is organized into four parts. First, the tops and leaves availability was assessed followed by the estimation of the area required for collecting these residues. This was followed by the assessment of surplus electricity potential from different scenarios depending on different technologies of cogeneration systems at sugar mills. Sugar mills in Thailand were grouped roughly based on different levels of boiler pressure and one sugar mill of each group was selected as the representative of that group for assessing energy balance (PDTI, 2011; Siemers, 2010). After that, the overall GHG emissions assessment was carried out for the entire life cycle of power generation from bagasse combined with tops and leaves. For tops and leaves, the supply chain (life cycle) includes collection, field hauling, road transport, shredding and storage whereas for bagasse, only storage is required as it is generated in the sugar mill itself. The avoided GHG emissions from replacing fossil-fuel power generation were also estimated. Finally, the cost assessment was conducted comprising the costs of tops and leaves supply chain as well as different configurations of power plants.

Tops and leaves quantity and area estimation

The quantity of tops and leaves generated was evaluated based on the quantity of sugarcane delivered to the mill using residue to product ratio (RPR) and surplus availability factor (SAF) as shown in Eq. (1) (Bhattacharya et al., 2005; Sajjakulnukit et al., 2005).

$$\text{Tops and leaves available (t)} = \text{Sugarcane amount (t)} \times \text{RPR} \times \text{SAF} \times \text{collection efficiency}. \quad (1)$$

RPR varies with plant structure, seasonality, harvesting methods, irrigation practices, soil quality, moisture content, and various other minor factors (Koopmans and Koppejan, 1998). The RPR of tops and leaves range between 17 and 30% as mentioned earlier. The average value of 22% was selected for estimating tops and leaves generation. The amount of tops and leaves that has to be left in the field for agricultural purposes (soil fertility and weeds control) depends on sugarcane variety, climate, soil, etc. (Hassuani et al., 2005). The SAF factor represents the proportion of unused amount of tops and leaves divided by the annual total amount of tops and leaves generated. A significantly large