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Biogas reduces the carbon footprint of cassava starch: a comparative assessment with fuel oil

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ABSTRACT

In the past 10 years, 90% of cassava starch factories in Thailand have switched from fuel oil to renewable biogas, to cover part of their energy needs. The environmental benefits of switching to biogas have not been assessed quantitatively. To alleviate this, this study assessed 100-year greenhouse gas (GHG) emissions, or carbon footprint (CF), of cassava starch production for four factories in Thailand. Key results demonstrate that biogas reduces the carbon footprint of the Thai cassava starch industry as a whole by 0.9–1.0 million tons CO_2eq/year, and highlight methodological precautions to collect LCI data and allocate GHG emissions between co-products with high moisture contents. The system boundaries included farm stage (production of cassava roots), transportation to factory and processing into native starch. The functional unit (FU) was one ton of native cassava starch at 13% water content. Biogas produced from the factory wastewater (95–200 m^3/FU) was the main source of thermal energy for starch drying, and for on-site electricity production when excess biogas was available. The total CF of cassava starch was in the range 609–966 kg CO_2eq/FU. Agricultural production contributed 60% of the carbon footprint, mainly from the use of nitrogen fertilizers. GHG emissions of root production varied widely due to (1) the diversity of farming practices even within a small radius (50 km), and (2) different agricultural yields in different regions. The contribution of the factory stage to the carbon footprint depended on the use of electricity, biogas and other fuels, ranging from 217 to 342 kg CO_2eq/FU. Allocation rules such as wet weight or dry weight basis allocations affected the results markedly.

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1. Introduction

Cassava starch production stands at an average 2.5 million tons/year in Thailand, and uses significant amounts of resources such as thermal energy, electricity and water, at respectively 1600–2500 MJ, 170–250 kWh, and 15–35 m^3 per ton of starch (Sriroth et al., 2000). In the past 10 years, 90% of cassava starch factories have switched from conventional fuel oil to biogas to cover parts of their thermal energy needs: Most of the biogas is used for starch drying and, if excess biogas is available, to generate on-site electricity. The adoption of biogas was driven by increasing prices of fossil fuels, which reduced the return on investment in biogas production facilities to 2–5 years (Plevin and Donnelly, 2004). Biogas is produced using the factory's wastewater as feedstock. Three main technologies exist (Chavalparit and Ongwandee, 2009) as follows: (1) Covered lagoon systems are most common and suitable for middle size starch factories (100–200 t starch/day), although larger scale factories can also use them. (2) Up-flow anaerobic sludge blanket (UASB) and (3) anaerobic fixed film reactor (AFFR) technologies are suitable for larger factories (200 t starch/day and above).

Biogas technology is an efficient method to treat wastewater and recover energy. Biogas technology is also suitable for solid organic waste, in particular agricultural or agro-industrial residues with high moisture content, which are difficult to convert by

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thermochemical processes such as combustion, torrefaction, pyrolysis or gasification. Biological digestion processes appear more efficient than thermochemical processes, with less environmental impacts and higher energy efficiency and recovery from the biomass (Fredriksson et al., 2006). Biological digestion also produces a nutrient-rich residual material (e.g., dead microorganisms, nitrogen, phosphorous, potassium, and other indigestible substances), which can be used as a fertilizer (Fredriksson et al., 2006; Oleskowicz-Popiel et al., 2012; Garg et al., 2005). To produce biogas via such a method, biomass is increasingly derived from organic materials, available in different forms such as energy crops, crop residues, and industrial organic wastewater (Mao et al., 2015). Biogas production is currently successful at large scale agro-industrial factories, such as cassava starch factories in Thailand (TÜV Nord Cert., 2011; South Pole Carbon Asset Management, 2009), but still has limitations at small scale to stabilize the supply of organic matter and the generation of methane (CH_4) (Amigun and von Blottnitz, 2010; Colin et al., 2007; Mai, 2006).

Biogas production typically includes two fermentation steps. First, acidogenic bacteria produce hydrogen, carbon dioxide, ammonia and organic acids. Second, methanogens convert these intermediate products into methane, carbon dioxide and minority gases (hydrogen sulfide, carbon monoxide, etc.). Methanogenesis is currently the main technology for anaerobic organic matter treatment (Mao et al., 2015). The emerging biohydrogen technology may further improve the efficiency of energy recovery from wastewater, by modifying the anaerobic digestion to obtain a gaseous end-product mainly composed of hydrogen gas (H_2). That is, the inoculums pretreatment (e.g., raising temperature to a value higher than room temperature and reducing pH to be more acidic) deactivate hydrogen-consuming microorganisms (i.e., methanogens) (Ghimire et al., 2015; Bakonyi et al., 2014; Pakarinen et al., 2008). Also, the use of a continuous bioreactor instead of a batch bioreactor is recommended to achieve higher expectable process efficiencies (Bakonyi et al., 2014; Wang and Wan, 2009).

Hydrogen as a sustainable alternative fuel has notable advantages over methane, including: (1) hydrogen has a higher energy content on mass basis in relation to methane (albeit a slightly lower energy content on volume basis), (2) less greenhouse gas is emitted from the hydrogen production, and (3) the combustion of hydrogen releases water vapor only (Balat, 2008). Nonetheless, Arimi et al. (2015) showed that by using organic-rich wastewater the hydrogen production has less energy recovery (the amount of energy yielded per the COD level) and less elimination efficacy of COD from the effluent (the amount of gas produced per the COD level). A two-fermentation steps process recovering both hydrogen and methane, combining the dark hydrogen fermentation and methane production, could recover more hydrogen and methane gases, leading to a higher energy recovery (Arimi et al., 2015). Yet other factors also need to be taken into account (e.g., the land use and the maintenance and operating cost) to compare the productions of hydrogen and methane.

In addition to the economic benefits, switching from fossil fuel oil to renewable biogas also has major environmental benefits, by reducing greenhouse gas (GHG) emissions. This reduction in GHG emissions has been assessed in the case of bioethanol production from cassava chips in Thailand (Moriizumi et al., 2012) and of waste management of manure and vegetal crops by-products in Europe (Fuchs and Kohlheb, 2014). However, the benefits of biogas produced by cassava starch factories have not yet been quantified, which is a significant gap in knowledge because the cassava starch industry as a whole produces large quantities of biogas and enables substantial savings in fuel oil and GHG emissions.

Consequently, the objective of this study is to assess the carbon footprint (CF) of cassava starch production using biogas, compared to the previous use of fuel oil. The added value of the study is to provide a benchmark of the environmental performance of current biogas technology at large scale. The findings are useful for researchers in the field of biogas production, and for processors of cassava and other agricultural materials, who work on (i) replacing fossil energies with cheaper, renewable and more sustainable sources of energy, and/or (ii) improving wastewater treatment and addressing methane emissions from untreated wastewater. Four cassava starch factories were surveyed in different provinces in the western (factories F1 and F2), central (F3) and northeastern (F4) regions of Thailand. The production capacity was 150–350 t starch/day/factory. The life cycle assessment (LCA) framework was used to conduct the environmental assessment.

2. Materials and methods

2.1. Description of the methodological approach

The carbon footprint assessment followed the four steps of a LCA study, as defined by the ISO14040 and ISO14044 standards (2006): (1) The goal and scope of the study were defined, including a description of the system boundaries and of the functional unit (FU). (2) The inputs and outputs of the system were inventoried in a quantitative and comprehensive manner (e.g. raw materials, energy, emissions, etc.). This inventory is referred to as life cycle inventory (LCI). (3) The GHG emissions were calculated using databases (e.g. Ecoinvent Center, 2011; JEMAI, 2012; TGO, 2011) of emissions factors to convert LCI data into emissions of CO_2-equivalent. This step is referred to as impact assessment. (4) Results were assessed for consistency. The LCI and calculations of GHG emissions followed additional guidelines from methods specific to carbon footprint assessments (TGO, 2011; PAS 2050, 2011; ISO/TS 14067, 2013). Lastly, the sensitivity of the results to the method of allocation (e.g. weight basis, economic basis) of the GHG emissions between the main product (starch) and the co-products was also assessed.

2.2. Goal and scope

The goals of the study were (1) to assess the greenhouse gas (GHG) emissions of cassava starch production from cassava root farming to cassava processing, with cassava starch (13% water content) as the end product; and (2) to assess the reduction in GHG emissions after adoption of biogas technology, compared to an equivalent scenario using fuel oil for starch drying. The functional unit (FU) was one ton of starch with 13% water content, packaged in polypropylene bags. The system boundaries include three phases of product lifecycle: agricultural production of cassava roots, transportation of raw materials to the factory, and cassava starch production at the factory (Fig. 1). The production of biogas from wastewater on the factory site was also included, as well as the generation of on-site electricity from biogas for the factories equipped with a generator (F1, F3, F4). All the volumes of biogas reported in this paper were expressed under standard temperature and pressure conditions (0 °C and 101,325 Pa). The infrastructures (factory buildings, machinery) were not included, because the GHG emissions from infrastructures were considered small compared to emissions from energy, water and materials inputs; particularly when related to the large quantities of starch produced over the 20–30 year lifetime of a factory.

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