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Case Study

Life cycle assessment on biogas production from straw and its sensitivity analysis

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HIGHLIGHTS

- This study executes a cradle-to-gate LCA study on biogas production from straw.
- The process has beneficial effect on synthetic environment.
- The negative impacts of this process on GHG emission are strengthened with time.
- Use of gas-fired power burning self-produced NG can create a clearer process.
- More focus shall be on efficient use of electricity and selection of CO_2 absorbent.

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ABSTRACT

This study aims to investigate the synthetically environmental impacts and Global Warming Potentials (GWPs) of straw-based biogas production process via cradle-to-gate life cycle assessment (LCA) technique. Eco-indicator 99 (H) and IPCC 2007 GWP with three time horizons are utilized. The results indicate that the biogas production process shows beneficial effect on synthetic environment and is harmful to GWPs. Its harmful effects on GWPs are strengthened with time. Usage of gas-fired power which burns the self-produced natural gas (NG) can create a more sustainable process. Moreover, sensitivity analysis indicated that total electricity consumption and CO_2 absorbents in purification unit have the largest sensitivity to the environment. Hence, more efforts should be made on more efficient use of electricity and wiser selection of CO_2 absorbent.

1. Introduction

Depletion of fossil fuel has attracted more attention since energy demand is annually increasing in the world. According to the statistics reports from British Petroleum (BP, 2010–2014), the reserves-to-production ratios of natural gas (NG) are no more than 65 years in the world and 30 years in China. This indicates an urgent need for new source of NG to satisfy the demand in the future. Meanwhile, greenhouse gases (GHG) emission mitigation is another challenge China is facing now. China has announced to make best efforts to cope with the peaking of CO_2 emissions around 2030.

Chinese government has encouraged the usage of non-fossil fuel sources recently (CNREC, 2015). Biogas produced from biomass, such as crop residues (Li et al., 2014a), animal manure (Tuesorn et al., 2013) and food waste (Brown and Li, 2013), would be an efficient approach to alleviate energy crisis and to reduce air pollution at the same time. Many studies have proved that biogas produced from straw would potentially be an alternative energy source (Buratti et al., 2013; Zhang et al., 2014).

China is a vast agricultural country, with abundant resources of agricultural waste. The amount of straw that can be collected annually is more than 700 million tons in China (Chen et al., 2010). Among these, about 122 million tons are combusted directly for heat while 206 million tons are left on the field or burnt outdoor (NDRC, 2011). Straw field burning would release significant amount of CO_2, CO, SO_2, NO_X and particulate matters, resulting in severe regional air pollution (Shen et al., 2009). Generating biogas from straw could not only ease the energy crisis but also make full use of waste and reduce air pollution. It could be the dominant treatment option of waste straw in China.

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Many researches have been carried out on biogas production from straw and its industrial application has been implemented in many countries (Dinuccio et al., 2010). However, Peter Fairley (2011) believes that over-all energy consumption and synthetically environmental impact of biofuels must be fully investigated to justify its sustainability. Life cycle assessment (LCA) is a widely used method that considers overall inputs, outputs and potential synthetically environmental impacts throughout a product's lifetime (ISO, 2006). An enormous amount of relevant researches have been published. Gnansounou et al. (2009) studied the life cycle GHG emission of three conversion technologies from wheat to bioethanol as transportation fuels. ESU-services Ltd. (Jungbluth et al., 2008) compared the synthetically environmental impacts among twelve biomass-to-liquid fuels systems. Wulf and Kaltschmitt (2013) executed a LCA study on hydrogen production for transportation. Two continued studies (Poeschl et al., 2012a,b) were carried out to investigate the life cycle environmental impact of multiple biogas production systems and their utilization pathways. And few literatures have concentrated on the effect of individual sub-processes during biofuel production. Morero et al. (2015) focused on the absorption-desorption sub-process and compared the life cycle assessment of using three different CO_2 solvents for biogas purification. Bacenetti et al. (2015) assessed the influence of energy density and transport distance of bio-methane production. However, inter-comparison among each sub-process has not been performed yet. Evaluating the synthetically environmental impact of individual sub-process will locate the most damaging sub-process during the biogas production and guide engineers to develop a more environmental-friendly biogas production process in the future.

Hence, this study assessed a process-based LCA of biogas production from straw to figure out which sub-process owed the most damage or benefit. Also, the sensitive analysis was employed to find sensitive factors on the results and to provide technical advices on cleaner production. Moreover, LCA has been significantly developed only since the last decades and it is still at a nascent stage in China. It is a great challenge and of importance to establish a localized inventory database in China. This case study will help provide a reference on biogas production for establishing localized LCA inventory database in China.

2. Methods

LCA is a widely used environmental assessment method and mostly applied to assess the environmental impact of a system, a product or one kind of service. This study executes a cradle-to-gate LCA of biogas production from straw. The use phase and end-of-life phase of produced biogas are not taken into consideration. This LCA study was carried out based on ISO standards (ISO, 2006) using Simapro software. There are four phases to conduct a LCA: goal and scope definition, life cycle inventory, life cycle impact assessment (LCIA) and interpretation (Curran, 2013).

2.1. Goal and scope definition

The first phase of executing life cycle assessment is Goal and scope definition. This study employs a cradle-to-gate LCA approach, because the use and end-of-use processes for NG will not differ for different manufacturing technologies (Pawelzik et al., 2013). The goal of this work is to assess the impact of individual sub-process on synthetic environment and GHG emission during biogas production from straw via anaerobic digestion technology and to figure out the most significantly damaging or most beneficial sub-process to environment. Moreover, the study will provide data for establishing the localized inventory database in China.

2.1.1. System boundary

A detailed system boundary diagram describes the scope of straw-based biogas production in Fig. 1. The system is divided into five units that are pre-treatment, fermentation, biogas purification, biogas residue disposal and auxiliary. In addition, environmental protection equipment is assembled in each unit to meet the strict environmental standards in China.

- In the pre-treatment unit, straw is transported by Lorries. As mentioned, a large amount of straw is disposed as waste in China. Hence, straw is seen as waste which does not cause any environmental impacts (Li et al., 2014b). This suggests that energy stored in straw is not taken into consideration in this study. Generally, the waste straw is left in the field after harvest and it is sundried before collection. The collected straw is firstly retted and grated into smaller size.
- Then the pre-treated straw is pumped into a fermentation tank where straw is anaerobically digested and the raw biogas is generated. The gas stream contains 60% CH_4. The residue after fermentation is separated into liquid slurry and semi-solid sludge which are both disposed in the biogas residue disposal unit. The liquid slurry is concentrated to generate phytonutrient and the wastewater with high concentration of COD (chemical oxygen demand) is discharged into oxidation pond. Wastewater from other units is also gathered into the oxidation pond. The mixed organic wastewater is recirculated into the fermentation tank. The semi-solid sludge is used to generate organic solid fertilizer via drying and prilling.
- Gas stream produced from fermentation unit needs to be purified before use. The other 40% of the biogas is consisted of about 35% CO_2, 1450 PPM H_2S, 3.5% water and less than 1.5% N_2. H_2S is removed as crude sulfur via catalytic desulfurization in a desulfurization tank. The crude sulfur produced in this step is retreated to recycle as one of the by-products: refined sulfur. CO_2 is firstly absorbed by MDEA at 50 °C and 2.0 MPa. MDEA is regenerated at 122 °C and 0.07 MPa where the high concentration CO_2 is released in the regeneration tank. Concentrated CO_2 is then captured by sodium hydroxide in the carbonating tank and sodium carbonate is acquired as another by-product. Lastly, the gas stream is dehydrated to remove the moisture. The biogas produced after purification step is consisted of 97.5% CH_4, less than 50 PPM CO_2, less than 4 PPM H_2S, 1 PPM water and less than 2.5% N_2. Finally, this biogas is compressed into Liquid Natural Gas (LNG) to be stored or transported.
- Heat, compressed air and nitrogen are supplied in the auxiliary unit. Heat is supplied from burning the boil-off-gas (BOG) and biogas produced from this process. Air is compressed into 0.8 MPa and Nitrogen is acquired from liquid nitrogen with a pressure of 0.7 MPa. Electricity comes from electric power station while water is provided by Municipal Water Distribution Network.
- Construction of buildings, manufacture of machines; tools and transportation are not taken into consideration. Also, environmental impacts caused from human behaviors are set out of the system boundary. Noise is also not considered since only the workers nearby is affected when the noise is below 80 dB.

2.1.2. Functional unit

Functional unit (FU) is the basis of calculation and the reference for normalization. Mass-based FUs and energy-based FUs are commonly selected in LCA studies of biofuels due to convenience. The FU of this article is defined as 1 ton of pre-dried straw.

2.1.3. Database and analysis methods

Simapro software contains many databases. Ecoinvent database (Frischknecht et al., 2004) is chosen as background data sources for