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Life-Cycle GHG Emissions of Cassava-Based Bioethanol Production

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Abstract

This study aims to assess the life-cycle greenhouse gas (GHG) emissions of cassava ethanol production system focusing on utilization of biomass and biogas as energy sources in the steam production process. Scope of life cycle assessment is "cradle to gate" and the functional unit of this study is 1 liter of anhydrous ethanol produced. The use of biogas from wastewater treatment system for steam production greatly affects the GHG reduction. The GHG emissions of bioethanol plant that uses biogas from wastewater for steam production is 0.548 kg-CO_2-eq/L-ethanol, while the bioethanol plant without biogas utilization is 1.031 kg-CO_2-eq/L-ethanol. From the result, the utilization of biogas in steam production insignificantly reduce the GHG emission, if primary fuel in steam production is biomass. In contrast, using biomass such as wood chip and rice husk substitutes for fossil fuel as primary fuel in steam production greatly affects to GHG emission reduction (approximately 96% reduction compared to literature).

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*Keywords:*life-cycle assessment, greenhouse gas, cassava, bioethanol.

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1. Introduction

At present, researches on renewable and sustainable resources have been encouraging because the energy consumption in the world and the depletion of fossil fuel reserves have increased instantaneously. Bio-ethanol is important renewable energy for transport since the oil price has been growing at the rapid rate. Thailand is an agriculture based country, the Thai government support the production of bioethanol from biomass to reduce oil import. In December 2005, gasohol use was at a high proportion by 17.4 percent of total gasoline selling [1]. Government has improved such the measures to keep promoting the gasohol production and consumption, e.g. ethanol pricing formulation, confidence-building measure, including a pricing measure. Up to November 2008, consuming of ethanol in Thailand would be in form of gasohol 95, gasohol 91, E20 and E85 at 11 million liters/day or as 1.11 million liters/day of ethanol [1]. In 2013, bioethanol consumption was 2.6 million liters/day, up 85.7% from the previous year, and 100% from 2009 [2]. In case, Thai government support to produce bioethanol from cassava, it is necessary to assess the environmental impact of bioethanol production.

From previous studies [3-6], Most of these studies assessed the environmental impact and life-cycle greenhouse gas (GHG) emissions of cassava-based ethanol production in Thailand that use fossil fuel as primary fuel in steam production. The result from these studies showed that the ethanol plants without wastewater treatment systems produce ethanol with GHG emissions that are higher than gasoline. The most of GHG emissions from the using coal for steam production and methane emission from wastewater. At present in Thailand, most the cassava based bioethanol plants have wastewater treatment system with biogas recovery and utilizing as steam energy source and substituted biomass for coal.

The aim of this study is to assess the life-cycle GHG emissions of cassava-based ethanol production system focusing on utilization of biomass and biogas as energy source in the steam production process.

2. Methodology

Life Cycle Assessment (LCA) is technique for evaluating the potential environmental impacts throughout product's life cycle (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling) [7]. LCA methodology used inthis study was based on ISO14040 framework, which is carried out in four distinct phases: (i) goal and scope definition, (ii) life cycle inventory analysis, (iii) life cycle impact assessment, and (iv) interpretation [8].

2.1. Goal and scope definition

This study aims to assess the GHG emissions of bioethanol production from cassava based on a lifecycle perspective; the functional unit (FU) of this study is 1 liter of 99.8% bioethanol.

Scope of life cycle assessment is "cradle to gate" including cultivation and harvesting of fresh cassava, fresh cassava and cassava chip transportation, cassava chip production, bioethanol conversion, by products processing and on-site waste management. The mixing process of bioethanol with gasoline, and fuel combustion stage are excluded in this study.

2.2. Life cycle inventory data

Most of data that used in this study were collected from actual site interview in Thailand such as fresh cassava farming, cassava chip processing, and bioethanol conversion. A summary of data sources is shown in Table 1. The details of each stage are described in following sections.

2.2.1. Fresh cassava cultivation stage

The sub-stages of fresh cassava farming activities included land preparing, seed planting, fertilizing, weeding, and harvesting. The background data of this stage were gathered from cassava farmer in the north-eastern region of Thailand and CO_2 emission from land use change was excluded in this study. The harvested fresh cassava roots are transported to nearby cassava chip processing factories.

2.2.2. Cassava chip production stage

The sub-stage of cassava chip production activities included weight measurement of harvested fresh cassava roots, cassava roots chopping, and cassava chip drying. The data in this stage were gathered and averaged from actual cassava chip processing factories in north-eastern region of Thailand.

2.2.3. Bioethanol conversion stage

The sub-stage of ethanol conversion in bioethanol plants included crushing, mixing, liquefaction, saccharification, fermentation, distillation, and dehydration. In this study, data of this stage were gathered from commercial cassava based ethanol plants in Thailand. The emissions from fuel combustion in steam production process, emissions from electricity used in plants, and water emissions after wastewater treatment were accounted.If biomass used as fuel in the boiler to produce steam, it gave no environmental burden but the data of biomass production was included. CO_2 emission from biomass combustion process was excluded according to carbon neutral rule.

2.2.4. Transportation stage

The sub-stage of transportation activities included the transportation of feedstock from the cassava field to the cassava chip factories, of cassava chip to the ethanol plant, and of chemical substances that were used in bioethanol plants. The data in this data were gathered from actual site interview and bioethanol plants.

Table 1. Data source for performing GHG emission analysis

Life cycle stage	Data source
Fresh cassava cultivation stage	Primary data collected from cassava farmer interview in north-eastern region of Thailand
Cassava chip production stage	Primary data collected from cassava chip processing factories
Bioethanol conversion stage	Primary data collected from cassava based bioethanol plantsand on site interview
Transportation stage	Primary data collected from cassava-based bioethanol plants and on site interview

2.3. Description of case studies

Table 2reviews the three cases of cassava ethanol plants in Thailand that were selected on the source of information obtained from a field survey. The plant production capacity is 40 million liters per year of 99.8% ethanol and feedstock for ethanol production is cassava chips from north-eastern region of Thailand.

Table 2. Description for each case studies

	Wastewater treatment	Biogas	Steam energy source
Case 1	Open pond	×	Biomass
Case 2	Anaerobic digestion	Utilizing	Biomass + Biogas
Case 3	Anaerobic digestion	Flaring	Biomass

2.3.1. Case study 1

This case study has the wastewater treated in open pond without biogas recovery systemandthe chemical oxygen demand (COD) of wastewater that generated is approximately 14 kg/m^3. This bioethanol plant uses biomass such as wood chip and rice husk as primary fuel for steam production. All electricity required for ethanol production is purchased from national grid.

2.3.2. Case study 2

This case study has the wastewater treated inMethane Upflow Reactors (MUR)with biogas recovery system. This bioethanol plant uses biomass such as wood chip and rice husk as primary fuel for steam production. For maximum benefit, this plant utilizes biogas from wastewater treatment system substituted to biomass in steam production. All electricity required for ethanol production is purchased from national grid.

2.3.3. Case study 3

This case study has the wastewater treated in MUR with biogas recovery system but this plant does not utilize biogas. This plant manages excess biogas from wastewater treatment system with flaring. This bioethanol plant uses biomass such as wood chip and rice husk as primary fuel for steam production. All electricity required for ethanol production is purchased from national grid.

2.4. Life cycle GHG emission factor

For performing the GHG emissionsassessment of bioethanol from cassava, we used the following source of emission factor to estimate the GHG emissions: GHG emission factors from Thai national database and Eco-invent database [9] for some items such as the production of fertilizers, herbicides, etc. The GHG emission factors for fuels, materials, and chemical substances are listed in Table 3. GHG emissions from fuel combustion calculated based on the IPCC Guidelines for National Greenhouse Gas Inventories [10].

Table 3. GHG emission factors for materials and chemical substances

Material and chemical substances	CO_2 emission factor	Unit	Source
Fresh cassava	0.0426	kg-CO_2eq./kg	On site interview
Urea	3.3036	kg-CO_2eq./kg	Ecoinvent 2.2
Sodium hydroxide	1.1148	kg-CO_2eq./kg	Ecoinvent 2.2
Sulfuric acid	0.1219	kg-CO_2eq./kg	Ecoinvent 2.2
Enzyme	1.1500	kg-CO_2eq./kg	Ecoinvent 2.2
Yeast	0.6170	kg-CO_2eq./kg	Ecoinvent 2.2
Poly aluminium chloride	0.2770	kg-CO_2eq./kg	Ecoinvent 2.2
Electricity	0.6093	kg-CO_2eq./kwh	Thai national database
Diesel	0.3282	kg-CO_2eq./kg	Thai national database

3. Results and discussions

3.1. GHG emissions of each case study

GHG emissions for casestudy 1, 2, and 3 are 1.026, 0.548, and 0.613 kg-CO_2-eq/L-ethanol, respectively. Focusing on the ethanol conversion stage, the GHG emission contribution could be shown in Table 4. For case study 1, the result showed that themajor GHG emissions come from CH_4 emission from wastewater approximately 50 percent of total GHG emissions and thesecond following GHG emissions from feedstock derivation. For case study 2, the result showed that the major GHG emissions come from feedstock derivation different from case study 1 because this was no emission from wastewater. In this case, CH_4 emission after wastewater treatment was merged into steam production because of the biogas utilization that substituted to biomass as primary fuel in steam production. For case study 3, the result showed that the GHG emissions come from feedstock derivation same as case study 2 and second following GHG emissions come from electricity that use in bioethanol plant. This case does not utilize biogas from wastewater treatment and manages excess biogas with flaring. However, emission from biogas flaring was 0.107 kg-CO_2eq/L-ethanol that was 17.5 percent of total GHG emissions.

Table 4. GHG emissions of 1 liter anhydrous ethanol production

Item contribution	Case study 1		Case study 2		Case study 3	
	kg-CO_2-eq/l-ethanol	%	kg-CO_2-eq/l-ethanol	%	kg-CO_2-eq/l-ethanol	%
Cassava chip derivation	0.246	24.0	0.246	44.9	0.246	40.2
Chemical derivation	0.027	2.7	0.027	5.1	0.027	4.5
Electricity	0.184	17.9	0.184	33.6	0.184	30.0
Steam production	0.029	2.8	0.072	13.1	0.029	4.8
Process water production	0.001	0.1	0.001	0.1	0.001	0.1
CH_4 emission from wastewater	0.521	50.8	0	0	0	0
Emission from biogas flaring	0	0	0	0	0.107	17.5
Transportation	0.018	1.7	0.018	3.2	0.018	2.9
Total	1.008	100	0.530	100	0.595	100

3.2. Effect of biomass and biogas utilization on GHG emissions

The GHG emissions for the three plant case studies compared with the results from literature [3] are shown in Figure 1In case of the previous study that use coal as fuel to produced steam in its own boiler, all electricity required for ethanol production is purchased from the National Grid, and has not wastewater treatment; total GHG emission is 2.075 kg-CO_2-eq/L-ethanol. By the way, total GHG emission of case study 1 is 1.026 kg-CO_2-eq/L-ethanol (approximately 50% reduction). In case of the previous study that had its own wastewater treatment system with biogas recovery. This plant produced steam in its own boiler, and the biogas recovered from the anaerobic wastewater treatment system was used as the primary fuel for steam generation. All electricity required for ethanol production was purchased from the National Grid. Total GHG emission of this ethanol plant from previous literature is 1.097 kg-CO_2-eq/L-ethanol. However, total GHG emission of case study 2 is 0.548 kg-CO_2-eq/L-ethanol (approximately 50% reduction).

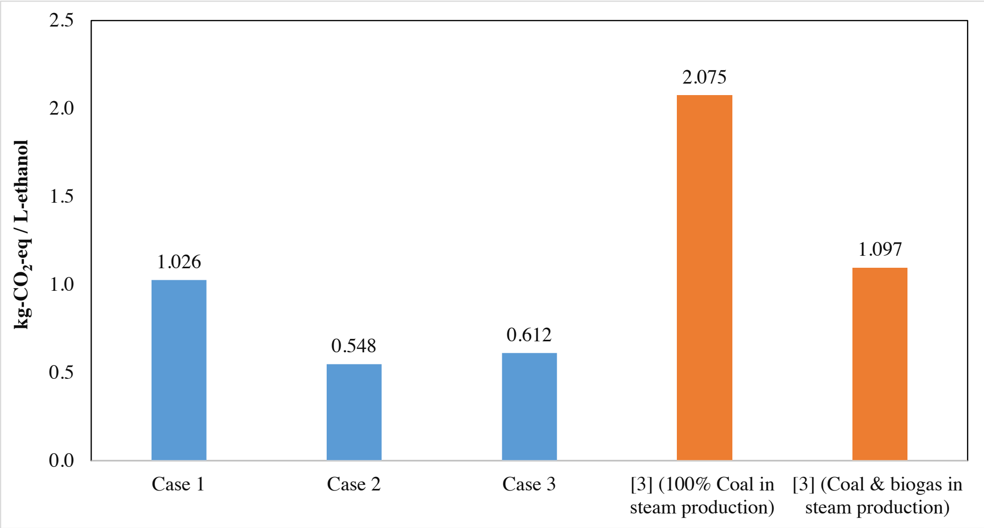

Fig. 1. GHG emissions for each case study.

Focusing on life cycle stage, cassava chip derivation and chemical substance derivation in this study are insignificantly less than the literature. However, electricity in this study are more than the literature. Focusing on steam production, the GHG emission of steam production from the literature [3] is 0.872 kg-CO_2-eq/L-ethanol. In this study, GHG emission of using biomass in steam production in is 0.029 kg-CO_2-eq/L-ethanol (approximately 96% reduction) as shown in Figure 2. Result from this study indicate that using biomass and biogas as energy sources in the steam production process could reduce GHG emissions of cassava-based bioethanol more than 50%.

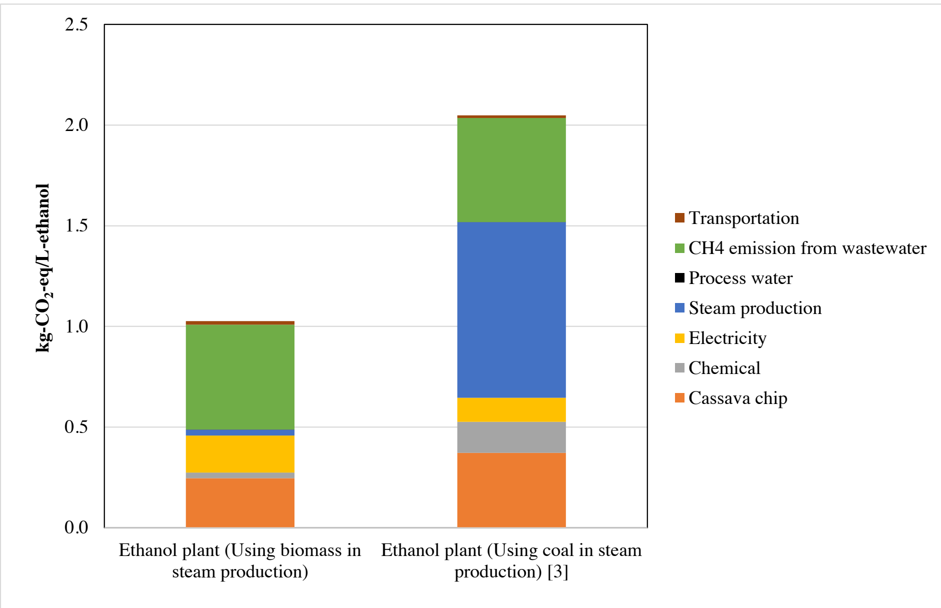

Fig. 2. Comparison of using biomass and coal as energy source in steam production.

4. Conclusion

The results showed that major emission caused from feedstock cultivation & processing for case study 2 is 46.4% of total GHG emissions and case study 3 is 41.4 % of total GHG emissions. While the major GHG emissions of case study 1 that has the wastewater treated in open pond is CH_4 emission from wastewater treatment. However, the utilization of biogas in steam production insignificantly reduce the GHG emission, if primary fuel in steam production is biomass. In contrast, using biomass such as wood chip and rice husk substitutes for fossil fuel as primary fuel in steam production greatly effects to GHG emission reduction. The results of GHG emission in this study should be determine by another factor such as plantation area, wastewater treatment system, and co-location plant case.

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