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Utilization of Biogas for Boiler System to Reduce Greenhouse Gas Emission from Distillery Factory

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Abstract

This research evaluates the greenhouse gas emission reduction from LPG saving due biogas utilization to fuel boiler. The Upflow Anaerobic Sludge Blanket reactor (UASB) has been used for stillage wastewater treatment. Thus, the net biogas production from this unit is 694,164 m^3/year. The biogas is mainly composted with 62.06 ± 4.07% of CH_4 and has heating value of 18,167.34 kJ/m^3 which can replace 34% of the consumed LPG for steam generation at boiler system. Utilization of biogas instead of LPG is associated with direct and indirect GHG emissions reduction by 3,478 tCO_2e/year (51.31%) and 198 tCO_2e/year (2.92%), respectively. A significant portion of GHG emission diminution associates with the direct GHG reduction by replacement of LPG at boiler system and rescinding of biogas flaring. Generally, the biogas utilization is found to be a promising technology in engagement the constraint on energy consumption situation and mitigating climate change.

Keywords : Anaerobic treatment; Biogas; Greenhouse gas emission; Renewable energy; Stillage wastewater; UASB reactor

Introduction

GHG emission reduction according the national policy

Thailand aims to reduce GHG emission by 20-25% from projected business-as-usual (BAU) level by 2030 to mitigate the impacts from climate change. The Climate Change Master Plan 2015-2050 (CCMP2015) reflects on climate change mitigation, adaption, capacity building and cross-cutting issues.

The key of identifying measures and allocates emission reduction targets is in responsibility to relevant agencies in energy, transport, industry, and waste management sectors. Thailand's greenhouse gas emission inventory in 2016 was 354,357.61 $GgCO_2e$ [1]. As shown in Figure 1, the main GHG emission was involved with energy sector by 253,895.61 $GgCO_2e$ (71.65%).

Renewable energy in Thailand

In 2015, the Alternative Energy Development Plan (AEDP) had been issued to promote alternative energy and reduce fossil fuel import or consumption such as oil and natural gas [2]. The overall target of this plan was to increase the share of renewable energy consumption to 30% by 2036. Currently, Thailand leads among developing countries with 500 MW of biogas installed capacity and set a goal to 600 MW within 2036 [3].

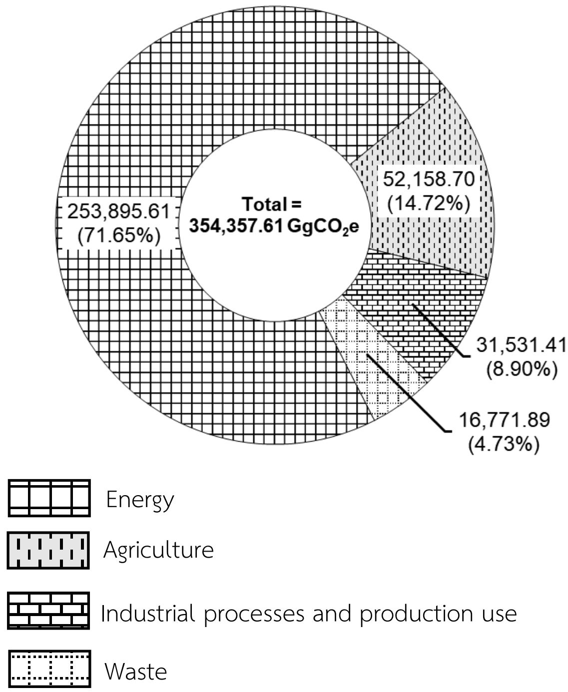

Figure 1 Thailand's Greenhouse gas emission in 2016

Biogas is a renewable energy technology that utilizes agricultural waste to produce a flammable methane gas which is important for various purposes. It is also clean and renewable energy which consists of methane (CH_4) 50%-70%, carbon dioxide 25%-45% and small amounts of hydrogen, nitrogen, and hydrogen sulfide. The calorific value of biogas ranges between 21 and 25 MJ/m^3 of biogas [4]. As a global warming potential, methane is 25 times stronger than carbon dioxide, even small leakages of biogas may be a strong negative effect on the total greenhouse gas emission [5].

The use of biogas as a source of steam generation

During the distillation process, several organic residues are generated, which can be used as feedstock for anaerobic digestion process. Anaerobic treatment of wastewater is currently realized on-site for most distilleries' factory. Appropriated technologies are employed for example, Upflow Anaerobic Sludge Blanket (UASB) and Expanded Granular Sludge Blanket (EGSB). Biogas can be used in a combined heat and power (CHP) facility for electricity and thermal energy or in a boiler for thermal energy. Globally, the International Energy Agency (IEA) estimates that 20% of current natural gas demand can be met sustainability by biogas utilization [6]. Previous study confirmed utilization of biogas instead of the natural gas for heat and electricity generation in the AD-CHP system. As a result, GHG emission was reduced by 113 kgCO_2e of every MWh electricity production (34% of GHG emissions) [7]. In case of utilization of biogas for heating purpose, biogas can replace up to 64% of the natural gas consumption and reduce direct GHG emissions by 27,748 tCO_2e (54%) and indirect GHG emissions by 11,389 tCO_2e (41% of direct savings) [8].

Thai government continues to promote alternative energy and reduces GHG emission. It is essential to thoroughly evaluate the performances of various type of factory and to identify in terms of minimizing GHG emissions. This research was studied about the greenhouse gas emission reduction by replacing LPG with biogas from stillage wastewater. The first scenario was open flaring of biogas. The second scenario was replacing biogas by LPG. The potential impact of biogas to reduce direct and indirect GHG emissions was observed in this study.

Methodology

Description of distilleries industry

The study area was at distilleries factory that located in central part of Thailand (July 2019 to June 2020). The capacity of this factory was 45 million liters/year. Distillation process was generated wastewater by 87,502.17 m^3/year. The residual liquid remaining after the initial distillation of fermented wort, also known as stillage wastewater. The stillage wastewater was uses as feedstock for biogas production plant (UASB). Originally, biogas was flared in vain. However, the current attitude and perception of biogas is the renewable energy source which can reduce fossil fuel consumption and mitigate global warming impact.

This distilleries factory uses electricity energy and LPG for steam generation. According the statistical reports from relevant factory, the boiler system has 87.7% of efficiency and generates 10,908 tons of steam per year by using LPG 675,205.2 kg (Heating Value of LPG was 49,848.2 kJ/kg reference by LPG specification from manufacturer). The utilization of biogas replacing LPG at boiler system can directly reduce GHG emission (LPG reduction and zero flaring of biogas).

Biogas production

The biogas production rate from stillage wastewater is calculated using Equation (1) [9].

$$\text{Biogas}_{\text{rate}} = \frac{\text{Biogas}_{\text{production}}}{(\text{COD}_{\text{inf.}}\text{-}\text{COD}_{\text{eff.}})\times \text{WWT}} \qquad (1)$$

Where:

$\text{Biogas}_{\text{production}}$ = Volume of Biogas produced [m^3]

COD_{inf} = COD of influent wastewater [g/m^3]

$\text{COD}_{\text{eff.}}$ = COD of effluent wastewater [g/m^3]

WWT = Volume of wastewater [m^3]

According the statistical reports from relevant factory, about 161.84 m^3 of biogas utilized at boiler system generates 1 ton of steam (functional unit), which equivalent to LPG 61.9 kg. The heating value of biogas is calculated based on the heating value of LPG (reference for LPG specification from manufacturer) as shown in Equation (2) heating value of biogas (kJ/m^3).

$$\text{HV}_{\text{biogas}} = \frac{\text{HV}_{\text{LPG}}\times \text{M}_{\text{LPG}}}{\text{V}_{\text{biogas}}} \qquad (2)$$

Where:

HV_{LPG} = Heating value of LPG [kJ/kg]

M_{LPG} = Mass of LPG uses at boiler [kg]

V_{biogas} = Volume of biogas uses at boiler [m^3]

Reduce greenhouse gas emission by replacing LPG with biogas

There are many industries accounting the GHG emissions adapting according to The Assessment of Carbon Footprint for Organization (ACFO), published by Thailand Greenhouse Gas Management Organization (TGO) in 2011. The GHG emissions are classified into 3 main "scopes".

Scope 1: GHG emission from activities under the direct control or ownership of companies such as fuel combustion and chemical use.

Scope 2: GHG emissions are associated with the generation of electricity, steam, fuel purchased by companies.

Scope 3: GHG emissions are indirect emissions associated with the value chain of companies, but do not arise from sources owned or controlled by the company.

There were 2 scenarios for the study of the greenhouse gas emission reduction by replacing LPG with biogas from stillage wastewater that shown in Figure 2. The first scenario was flaring of biogas. The second scenario was replacing LPG by biogas. The potential impact of biogas to reduce direct and indirect GHG emissions was observed in this study.

Direct greenhouse gas emission

The methodologies for assessment of GHG emission base on ISO 14064-1: (2006). The activity data have been obtained from statistical reports from relevant factory and reviewed by practitioners. Emission factors (EF) of each activity data were derived using the default conversion factors from IPCC Guidelines for National Greenhouse Gas Inventories (2006). The CO_2 equivalent (CO_2e) was reported for GHG emission by Equation (3).

$$\text{GHG emissions} = \text{Activity data} \times \text{EF} \qquad (3)$$

Methane capture from anaerobic wastewater treatment for utilization or flaring (T-VER-METH-WM-01 Version 04), published by TGO [10] and Methodological tool: Project emissions from flaring (Version 03.0) [11] have been used as a calculation tool for direct GHG emission from flaring of biogas (Equation (4)).

$$GHG_{flaring} = M_{biogas} \times (1\text{-}FE) \times GWP_{CH_4} \qquad (4)$$

Where:

$GHG_{flaring}$	=	GHG emission from flaring of biogas [$kgCO_2e$]
M_{biogas}	=	Mass of biogas to flaring [$kgCH_4$]
FE	=	Flaring efficiency (Open flare Efficiency = 0.5, Enclosed Flare Efficiency = 0.9)
GWP_{CH4}	=	Global warming potential of methane for a 100-year timescale

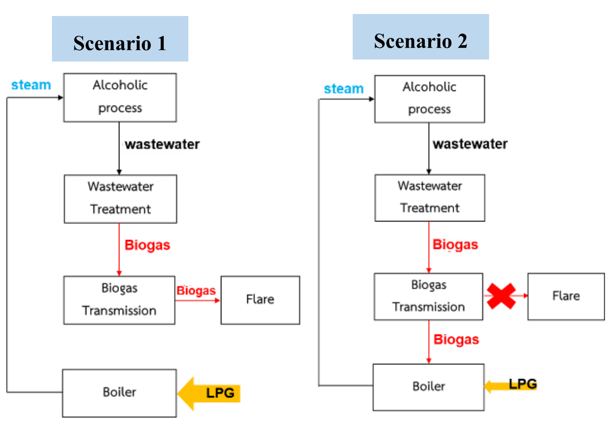

Figure 2 Schematic of 2 scenarios considered in this study

IPCC 2006 (Volume 2, Energy) has been used as a calculation tool for direct emission from biogas combustion. The combustion of biogas produces the following greenhouse gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Emissions of these gases from stationary combustion sources depend upon fuel characteristics (e.g., calorific value). The IPCC Guidelines provide default stationary combustion emission factors, which assume no emission controls are in place for steam generation.

Equation (5): Emission factor of biogas combustion ($kgCO_2/m^3$ of biogas)

$$EF_{biogas} = HV_{biogas} \times \begin{bmatrix} (DEF_{CO_2})+(DEF_{CH_4}\times GWP_{CH_4})+ \\ (DEF_{N_2O}\times GWP_{N_2O}) \end{bmatrix} \quad (5)$$

Where:

EF_{biogas}	=	Emission factor of biogas combustion to energy [$kgCO_2/m^3$ of biogas]
HV_{biogas}	=	Heating value of biogas [TJ/m^3]
DEF_{CO_2}	=	Default emission factor of carbon dioxide [54,600 $kgCO_2$/TJ]
DEF_{CH_4}	=	Default emission factor of methane [1 $kgCH_4$/TJ]
DEF_{N_2O}	=	Default emission factor of nitrous oxide [0.1 kgN_2O/TJ]
GWP_{CH_4}	=	Global warming potential of methane for a 100-year timescale
GWP_{N_2O}	=	Global warming potential of nitrous oxide for a 100-year timescale

Indirect greenhouse gas emission

The ACFO in above mention has been used as a calculation tool for indirect GHG emissions (electricity and LPG consumption). The emission factor of electricity and LPG consumption were 0.5986 $kgCO_2$/kWh and 0.8582 $kgCO_2$/kgLPG, respectively [12].

Result and Discussions

Performance of UASB reactor

Fluctuation of UASB effluent flowrate were shown in Figure 3. The box plot showed maximum, minimum (top and bottom dot) and average values (middle dot in the box). The highly fluctuated characteristics of UASB effluent flowrate can be observed. The highest effluent flowrate from the UASB reactor was recorded at 595 m^3/d (November 2019) due to the cleaning process and modified fruit wine production line. In December 2019-March 2020, factory produced several of products such as rice wine, fruit wine or whisky owning to the customer order. The stillage wastewater was relied on the waste streams generated from distillery batches of each products. Thus, the production of various products caused high variation flowrate of stillage wastewater. The full capacity operation was in March 2020, generated effluent 8.3-8.6 m^3/m^3 of products. According to the previous research, wastewater generated from this kind of processes was in ranges from 2-14 m^3/m^3 of wine produced [13]. In contrast, the lowest effluent flowrate was only 9 m^3/d (April 2020) because factory was annual shutdown/turnaround. Sometimes, there were no waste streams discharging from distilleries manufacturing lines, so the UASB reactor must conduct internal circulation.

As shown in Figure 4, COD concentrations of UASB reactors were plotted as a background of COD in the influent and effluents. The average influent COD concentration was 34,404.42 ± 7,001.6 mg/L. The highest influent COD concentration recorded was 43,091 mg/L (September 2019), while the lowest was at 19,376 mg/L (November 2019). The average effluent COD concentration was 8,410.25 ± 1,954.40 mg/L. The highest effluent COD concentration recorded was 11,373 mg/L (February 2020), while the lowest was 4,002 mg/L (November 2019). According to the literature, the influent COD concentration was increased, the COD removal rate

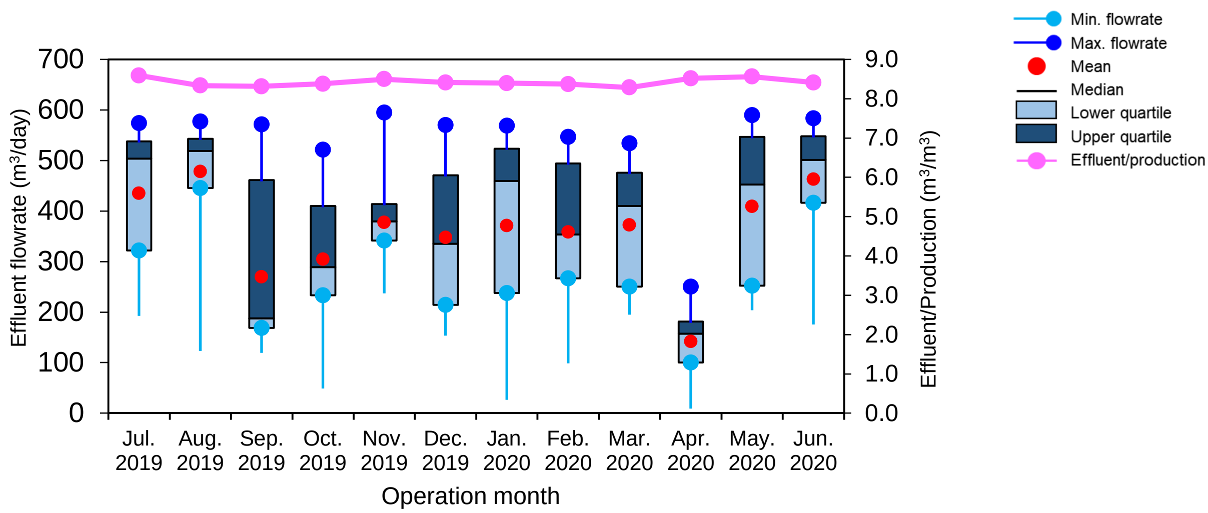

Figure 3 Box plot of UASB effluent flowrate

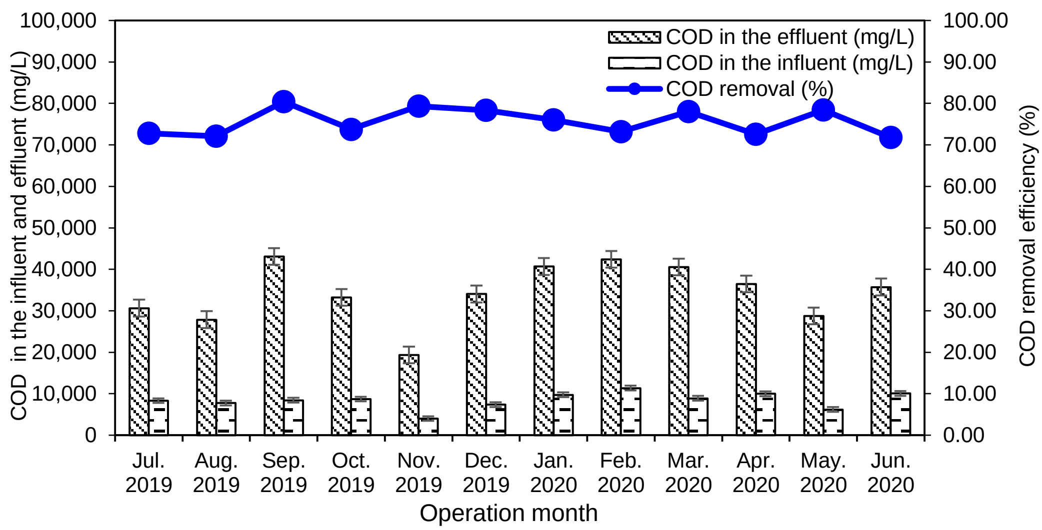

Figure 4 COD in the influent & effluent of UASB and removal efficiency

was reduced [14]. From December 2019 to February 2020, the COD removal rate was still high. High COD concentration of wastewater and sufficient removal efficiency generated sufficient methane gas which provided for internal circulation. The UASB reactor's performance was stable and tolerated with fluctuated condition. As shown in Table 1 and Figure 5, the performances of the UASB reactor was performed in terms of consistent COD removals rate on 75.58 ± 3.19%. According to the other studies as shown in Table 1. The COD removal rate of this study was mostly lower than the others. It is known that COD removal rate depend on initial COD, pH and temperature. The production of various products was generated high variation flowrate of influent wastewater and effected on performance of UASB reactor. Also, pH of influent was ranged from 3.37 to 4.24 (appropriate pH condition for methanogenic bacteria is 6.8-7.0).

Table 1 Performance of biogas production in this study compared to other studies

Case study	Products	%COD removal	Biogas production (m^3/kgCOD)	Methane production ($m^3 CH_4$/kgCOD)	$\%CH_4$
UASB (this study)	liquor, wine, whisky, brandy	75.58±3.19	0.31±0.13	0.19±0.08	62.06±4.07
Cruz-Salomón, A. *et al.* [15]	Comiteco (native liquor)	82-90	0.31	0.11±0.05	67
Zahedi, S. *et al.* [16]	Sherry wine	48-66	0.38	-	65
Zupančič, G.D. *et al.* [17]	Beer	82.6±3.77	0.461±0.115	0.25	77.4±1.96
Enitan, A. M. *et al.* [18]	Beer	78.97	0.485	0.32	65.9
Lin, J.C.-T. *et al.* [19]	Malt whisky	94.8±3.0	0.610	-	-
Jáuregui-Jáuregui, J. A. *et al.* [20]	Tequila	90	0.357	-	75

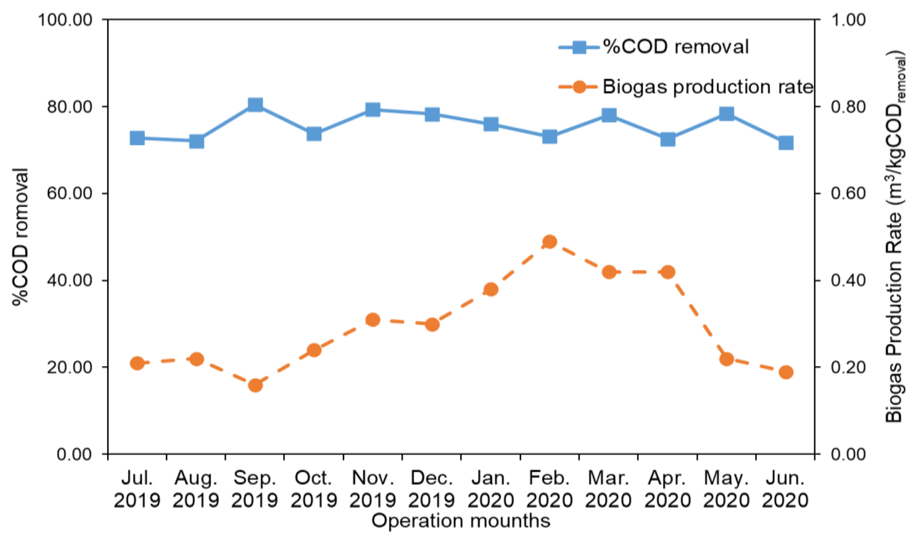

Figure 5 COD removal and biogas production rate

Biogas production and composition are shown in Table 1. Normally, biogas from UASB reactor commonly composes of higher-grade methane and lower concentration of carbon dioxide, due to the high solubility of this gaseous compound in the liquid. The calculation biogas production rate according to equation (1) resulted 0.31 ± 0.13 m^3 of biogas/$kgCOD_{removal}$. The methane production rate was 0.19 ± 0.08 m^3 of $CH_4/kgCOD_{removal}$. The biogas generated in UASB reactor was mainly composted of 62.06 ± 4.07% of CH_4. According to the other studies, the biogas production rate was 0.31-0.61 m^3/kgCOD, the methane production rate was 0.11-0.32 m^3 of $CH_4/kgCOD_{removal}$, and methane content (CH_4) was ranged from 65-77.4%. The theoretical methane production rate 0.35 $m^3 CH_4$ obtained from the chemical ratio of 1 kg COD removal. The biogas production rate and methane content of this study were the lowest (reported in Table 1).

Also, methane production rate was lower than theoretical methane production rate. This was attributed to the fluctuated and shock of substrate characteristics. The UASB reactor received wastewater from various production process that affect the methanogenic activities. The Methanogens are more sensitive to their environment than Acidogens. Acidogens can survive under a wide range of conditions while Methanogens are more demanding. Under the uncontrolled conditions, Acidogens were predominant, acid was formed and rarely converted to biogas. However, it is important to note that the observed range has a high variation, due to differences in the reactor type, the operation mode, substrate characteristics and to the microalgae species present in the system.

Biogas can be considered as fuel because of greater than 45% methane concentration. As a result the heating value of biogas could be calculated by the equation (2) (18,167.34 kJ/m^3 of biogas). The produced biogas could replace 34% of the consumed LPG for steam generation at boiler systems.

Greenhouse gas emission reduction

Greenhouse gas emission of each activity of scenario 1 was calculated by equation (3). Except the GHG emission from flaring of biogas was calculated by equation (4). The total greenhouse gas emission was 6,779 tCO_2e/year as shown on Figure 6. Direct GHG emission in Scenario 1 was 6,010 tCO_2e/year (88.66%), mostly from biogas flaring (3,387 tCO_2e/year). Indirect GHG emission was 769 tCO_2e/year (11.34%), mostly from LPG consumption by 579 tCO_2e/year.

Greenhouse gas emission of each activity of scenario 2 was calculated by equation (3). Except the GHG emission from biogas combustion at boiler system was calculated by default emission factors from equation (6) that result 0.9914 $kgCO_2/m^3$ of biogas. The total greenhouse gas emission was 3,103 tCO_2e/year as shown in Figure 6. The chemical use and electricity of both scenarios were the same consumption, thus the GHG emission from chemical use and electricity were the same values. However, direct GHG emission in Scenario 2 was 2,532 tCO_2e/year (81.60%). The direct GHG emission is mostly from

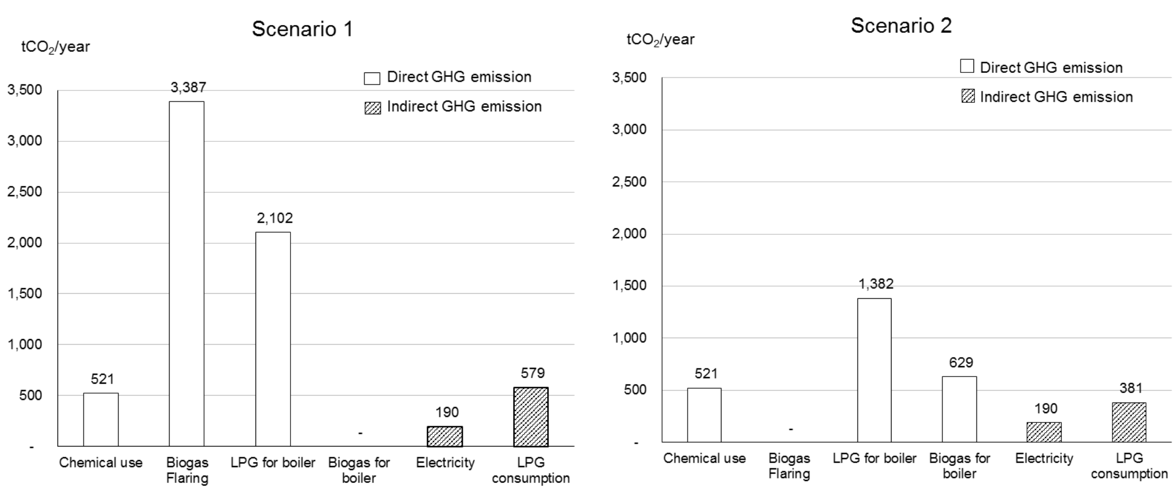

Figure 6 Greenhouse gas emission in scenario 1 and 2

LPG for boiler (1,382 tCO_2e/year). Indirect GHG emission in scenario 2 was 571 tCO_2e/year (18.40%). The indirect GHG emission is mostly from LPG consumption (381 tCO_2e/year). Both biogas utilization and reduction of LPG consumption are associated with direct and indirect GHG emissions reduction by 3,478 (51.31%) and 198 tCO_2e/year (2.92%), respectively. The total GHG emission reduction by replacing LPG with biogas for boiler is 3,670 tCO_2e/year (54.23%).

In this study, biogas was contained 62.06±4.07% of CH_4 and the heating value was 18,167.34 kJ/m^3 Biogas. The greenhouse gas emission by functional unit (1 ton of steam) of scenarios 1 and 2 were 0.62 and 0.28 tCO_2e/functional unit, respectively. The total GHG emission reduction by replacing LPG with biogas for boiler is 0.34 tCO_2e/functional unit. In previous study, biogas production volume of 1,300 m^3 was used for electricity generation via co-generation motor (2,800-4,100 kWh) [16]. The potential of 1 m^3 of biogas was possible to generate 2.15-3.15 kWh of electricity. On the other hand, the biogas production of 165.63±71.44 L/kgCOD was used for heat generation at boiler. The heat balance was 1.945 kWh/d in average [21]. The potential of 1 m^3 of biogas was possible to generate heat of 6.78 kWh. While, this study use biogas to generate steam of 4.54 kWh/m^3 Biogas. It is shown that biogas produce from stillage wastewater is possible to use as renewable energy source and reduction the greenhouse gas emission.

Thailand LPG consumption for industry sector was 611,950 tons/year in 2020 [22] and GHG emission was involved with energy sector by 31,531.41 $GgCO_2e$/year. The utilization of biogas for boiler system to reduce greenhouse gas emission from distillery factory would further reduce Thailand LPG consumption by approximately 0.4% (saving 231.38 tons/year) and reduce Thailand GHG emissions by 0.012% (saving 3.68 $GgCO_2e$/year).

Furthermore, biogas was used to replace LPG with original UASB reactor and boiler system. The factory was only invested biogas pipeline from UASB reactor to boiler system. The investing cost was expected 1,612.4 USD. The Utilization of biogas reduced LPG consumption 231,382.2 kgLPG/year, the price of LPG was 0.61 USD/kgLPG [23]. It means saving an annual cost of around 140,799.2 USD/year.

Conclusion

The results showed that the scenario 2 was more environmentally friendly alternative, while the biogas flaring in scenario 1 was worse scenario. It is shown that biogas from stillage wastewater is possible to replace the LPG consumption in boiler system. As a result, utilization of biogas has positive impacts on the environment issue, such as a significant greenhouse gases emission, risk of contamination of groundwater or the surface water resource reduction, which considerably reduces problems for local agriculture. Moreover, the digested sludge from anaerobic process is an excellent soil amendment and its nutrient supply could replace all the chemical products added to the soil, reducing pollution of this type.

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