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Socio-economic and Environmental Impacts of Bioethanol Production from Sugarcane (*Saccharum officinarum*) and Molasses in the Philippines

ABSTRACT

As the Philippine bioethanol industry reaches a decade and the debate on what bioethanol blending shall be imposed, this study assessed the socio-economic and environmental impacts of domestic bioethanol production parallel to the objectives of the biofuels law. Bioethanol production in the country has generated significant jobs or an estimated jobs of about 2,073 based on the actual bioethanol processing data for Crop Year (CY) 2017-2018 for the three bioethanol production systems (BPS) studied; and could potentially reach 10,620 jobs if mill capacities of the two bioethanol plants are met. Additionally, bioethanol industry was perceived to have a positive change for sugarcane farmers in terms of employment opportunities and cash income from bioethanol-related operations. The domestic bioethanol industry has even opened additional revenues to bioethanol-related industries of about PhP 1.2 B (23.9 M USD) for CY 2017-2018 and could even reach to PhP 3.0 B (60.4 M USD) if bioethanol plants can attain its installed mill and cogeneration capacities. Environmental impact assessment study, on the other hand, revealed that domestic bioethanol production can reduce GHG emissions by about 68 to 91% for the four BPS evaluated, compared to business-as-usual scenario of using fossil fuel.

Key words: *sugarcane bioethanol, molasses bioethanol, socio-economic impacts, environmental impacts, Philippine bioethanol*

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INTRODUCTION

Republic Act No. 9367, otherwise known as the “Biofuels Act of 2006,” was enacted primarily to reduce the country’s dependence on oil importation by mandating an increasing blend of biofuel with petroleum. The law also aims to mitigate toxic and greenhouse gases (GHGs) and boost the country’s rural economy by promoting the use of biofuels from indigenous resources.

Based on literature review, bioethanol production across the globe has shown positive environmental and socio-economic benefits. According to the study of *Munoz et al.* (*2013*), bioethanol is preferred over gasoline or fossil-based ethanol from a GHG perspective. Moreover, socio-economic impact studies of bioethanol production in Thailand suggest that bioethanol production has higher job generation than gasoline to about 17-20 times (*Silalertruska and Gheewala 2011*), and in general, has advantages on income generation (*Papong et al. 2017*).

For almost ten years from the implementation of the law, the Philippine biofuel industry has shown progress. Particularly for bioethanol, local capacity grew twelve times from 30 million liters per year (MLPY) in 2009 to around 365 MLPY in 2018 (*DOE 2018*). This translates to about half of the bioethanol requirement for the current mandate of E10 in 2018; while the remaining 50% of bioethanol requirement is imported. Although bioethanol blending is planned to increase from E10 to E20 in 2020, the Department of Energy (DOE), as the chair of the National Biofuels Board (NBB), recommended to review the bioethanol mandate through its new roadmap until 2040 due primarily to insufficient feedstock supply and high local price of bioethanol.

Currently, there are two feedstocks - namely, sugarcane and molasses, that are being utilized in the Philippines for bioethanol production. The national average sugarcane yield for crop year (CY) 2016-2017 is 66.5 Mg ha^{-1} with a total sugarcane plantation of about 413,472 ha and an average crop cycle of 12 months; wherein sugarcane land intended for bioethanol production is around 5,000 ha (*Gumera 2017*). This hectarage only translates to about 23 MLPY bioethanol, or about 6% of the bioethanol production capacity for an ethanol yield of 70 L Mg^{-1} cane stalks. On the other hand, molasses is a by-product of sugar production. Based on CY 2017-2108 data of SRA, average molasses recovery in the country's sugar mills is about 4% of the total sugarcane milled and a molasses production volume of about 1.1 Pg^{-1} (*SRA 2018*). This translates to 276 MLPY bioethanol or about 76% of the bioethanol production for an ethanol yield of 245 ML Mg^{-1}.

Bioethanol price is largely dependent on its feedstock price. In CY 2017-2018, the average bioethanol price is PhP 50.96 L^{-1} (USD 1.02 L^{-1}) and 55% (PhP 28.01 L^{-1} or USD 0.56 L^{-1}) is for feedstock cost alone. The average sugarcane and molasses prices are PhP 1,920 Mg^{-1} (USD 38.40 Mg^{-1}) and PhP 6,200 Mg^{-1} (USD 124.00 Mg^{-1}), respectively, for CY 2017-2018 (*SRA 2018*).

As the bioethanol industry reaches a decade and as the debate strengthens on what bioethanol blending shall be imposed, it is an opportune time to assess if the objectives of the law are being met. Hence, this study examined bioethanol production of four domestic bioethanol processing plants which served as a basis for the preliminary assessment of the bioethanol industry's contribution to the country's rural economy and climate change mitigation efforts.

Particularly, the socio-economic impact assessment aimed to determine jobs created, evaluate the changes in income, employment and standard of living of sugarcane farmers, and estimate additional revenue generated by bioethanol-related industries as a result of the four bioethanol industries under study. Meanwhile, environmental impact study determined the global warming potential (GWP) or carbon footprints of the four bioethanol production systems and the avoided GHG emissions or percentage of GHG emission reductions of these four bioethanol production systems with respect to its fossil fuel equivalent.

MATERIALS AND METHODS

Bioethanol Production Systems

To avoid breach of confidentiality agreement and to protect the use of corporate data, this study did not disclose the names of the four bioethanol plants investigated but rather used codes to refer to the four different bioethanol production systems (**Table 1**).

Bioethanol Production Supply Chain in the Philippines and the Scope of the Study

Given the objectives or focus of the socio-economic impact assessments, bioethanol production supply chain was mapped out for analysis to determine the key players, parameters and data to be gathered, and the scope of the study.

The bioethanol production supply chain starts from sugarcane plantation up to the use of 10% bioethanol-blended gasoline, as mandated under the Philippine biofuels law (**Figure 1**). A cradle-to-grave bioethanol system boundary (enclosed in dashed lines) in was applied for the environmental impact study (**Figure 1**). However, for the socio-economic study, the scope ends after the production of pure bioethanol at the gate of a bioethanol processing plant or cradle to gate analysis (refer to black boxes in **Figure 1**).

Note that the supply chain shows both the sugarcane and molasses streams as feedstocks for bioethanol production in the country (**Figure 1**). Also, products and co-products streams and their respective markets were analyzed.

Table 1. Basic information of the four bioethanol production systems under study.

Code	Feedstock	Bioethanol Production Capacity (MLPY)	CO_2 Production ($Mg\ CO_2\ d^{-1}$)	Electricity Rated Capacity (MW)	Co-generation Feedstock
BPS 1	Sugarcane and/or Molasses	40	48	7.4[1]	Bagasse, Biogas and/or Woodchips
BPS 2	Sugarcane and/or Molasses	54	N/A	19[1]	Bagasse, biogas
BPS 3	Molasses	30	78	4[2]	Concentrated Distillery slops[3], coal
BPS 4	Molasses	30	N/A		Bagasse

[1] Producing electricity for facility consumption and for income generation
[2] Producing electricity for facility consumption only
[3] This is produced from evaporating the distillery slops (or the high organic matter wastewater after distillation)

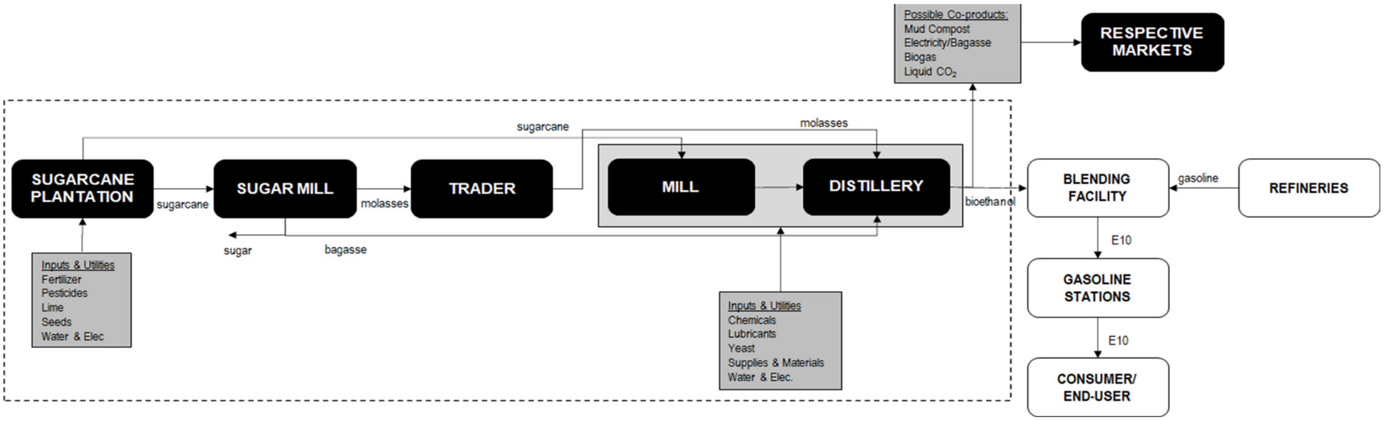

Figure 1. Bioethanol production supply chain in the Philippines.

Data Gathering

Data gathering was conducted between August to November of 2018. The first type of data gathered was the transactional or administrative data. These data, which include municipality profiles, feedstock production, distribution and price history, list of farms and farmers, plant description and processing details, and bioethanol supply and price history, were collected from government agencies (i.e., Sugar Regulatory Administration), local government units (LGUs), bioethanol processing plants, and from available journals. Meanwhile, the second type of data, known as residual data, was gathered from survey, focused group discussions (FGD) and key informant interviews (KII).

Survey was conducted to assess socio-economic impact of bioethanol production to sugarcane farmers. The number of farmers sampled was determined based on a tolerable margin of error for estimates of major variables,ε the variability of the population units and the desired level of significance,α. Given these factors and conditions, the sample size was computed using equation 1.

$$n_{SRS} = \frac{n_0}{1+\frac{n_0}{N}}, \text{ where } n_0 = \left(\frac{z_{\alpha/2}S}{\varepsilon}\right)^2 \qquad (1)$$

where $Z_{\alpha/2}$ is the abscissa of the standard normal distribution at α/2, S is the population standard deviation and N is the total number of population units in the sampling frame. When the population standard deviation was not available, then the estimate was based on the sample standard deviation derived from similar existing surveys. This initial sample size was further inflated by 5% to cover for any refusals or other types of non-response.

Since the variability in socio-economic characteristics and perceptions of farmers could be influenced by the size of their farms and the distance to the bioethanol distillery, farmers were classified according to the combination of these two factors. The final sample size defined above was then allocated equally across these groups to allow better comparison.

For BPS 1, the targeted sample size was 158, of which the median was determined to be 2.17 ha and 33 km (**Table 2**). Eighty-six of the targeted sample size were below median and median to less than 20 ha, while 72 were from 20 ha or more.

On the other hand, for BPS 2, sample size determination was not possible since no sampling frame was provided due to data confidentiality. The survey was administered to randomly selected sugarcane planters who attended the sugarcane planter's meeting organized by the Sugar Regulatory Administration (SRA).

FGDs were conducted to small and medium-to-large farmers of BPS 1 and BPS 2, represented by 5-8 sugarcane farmers per class size. In general, data gathered from FGDs are labor requirements and costs per farm activity, farm inputs (e.g., fertilizer, pesticides and herbicides) application, costs and sources, and farm fuel use and mechanization.

Lastly, KIIs were performed to the four bioethanol processing plants key personnel (e.g., plant manager,

Table 2. Distribution of sugarcane farms in the sample across distance and area groups.

Distance (km)	Area (ha)		
	< 2.17	2.17 to < 20	≥ 20
≤33	22	21	38
>33	22	21	34

human resource officer, supply and procurement officer) and molasses traders. Data obtained from the bioethanol processing plants include actual production data including co-products and by-products for 2017-2018, raw materials, chemicals and other inputs, energy (both heat and electricity) requirement, process flow chart, waste utilization practices, logistics as well as the total human resources of the processing plant including its compositions. Meanwhile, molasses traders were interviewed to determine their pricing scheme, inventory, production costs and market.

Data Analysis

After the questionnaires were finalized, dummy tables of the analysis that were implemented were developed based on the study objectives. These dummy tables are plans on how to represent the summary statistics that are required to address the study objectives. These consisted of descriptive statistics of socio-economic characteristics of farmers, historical trends of administrative data, summary of focus group and key informant interviews, classified accordingly. As warranted, cross-tabulation across size of farms and distance of farms were not included.

After the data from the surveys have been processed and validated, and survey weights have been determined, preliminary analysis was conducted. Comparative analysis across farm sizes and distance; and across bioethanol distillery were also undertaken.

Socio-Economic Impact Assessment

Socioeconomic impacts of bioethanol industry were analyzed at three levels: farmer level, both small farmers and large farmers; traders; and processors/millers. At the farmer level, the study employed various analytical tools to assess the impacts. First, a paired comparison t-test of quantitative impact indicators before and after the distillery establishment. Second, a test of proportion and test of independence for qualitative or categorical impact indicators.

Job generation, on the farmer level, was computed based on the results of the focus group discussions among farmers. Meanwhile, jobs reported from the processing side were determined from key informant interviews in the bioethanol plants. Note that only direct jobs were considered in the analysis.

Impact analysis for the traders was in terms of marginal changes in the inputs and outputs employed in relation to bioethanol trading activities. This analysis used primary data from FGD and KII as well as administrative data. Similar analysis was done for the processors/millers.

Environmental Impact Assessment

Life cycle assessment (LCA) approach was employed to analyze the environmental impacts of bioethanol production based on its global warming potential (GWP) or carbon footprints and the GHG avoided or gained compared to its fossil fuel equivalent. Environmental LCA is a well-known methodological tool which provides the holistic inventory of environmental impacts of a given product along its production chain, including relevant energy and material inputs and environmental discharges. It also provides an adequate instrument for environmental decision support (*UN Environment Life Cycle Initiative 2018; Jolliet et al. 2014*).

Functional Unit. Since bioethanol as a commodity is commonly being quantified on a per liter basis, the functional unit used for this study to determine the GWP of bioethanol production in the Philippines and its GHG emission reduction potential is kilograms carbon dioxide equivalent for every liter of ethanol ($kgCO_2e$ $L\text{-ethanol}^{-1}$)

System Boundary. Bioethanol supply chain in the country mainly differs on the type of feedstock being used for bioethanol production. In the Philippines, only two feedstocks are currently being used, namely, molasses and sugarcane. Therefore, two system boundaries were outlined for this study (**Figure 2**). These system boundaries follow the cradle-to-grave analysis (i.e., feedstock cultivation, processing, distribution, and use).

Carbon Life Cycle Inventory. In principle, life cycle inventory is simply the summation of all the GHG emissions classified under Scopes 1, 2 and 3 within the defined system boundary. As defined by the GHG Protocol Product Life Cycle Accounting and Reporting Standard (*World Resources Institute and World Business Council for Sustainable Development 2011*), scope 1 and scope 2 emissions are direct emissions from owned or controlled sources and indirect emissions from the generation of purchased energy, respectively, while scope 3 emissions are all indirect emissions (not included in scope 2) that occur in the value chain of a product, including both upstream and downstream emissions. The general equation to compute for the GWP or carbon footprint of bioethanol is shown below:

$$GWP_{ethanol}\left(\frac{kgCO_2e}{L}\right) = \sum S1 + \sum(X_{s2})(EF_{X_{s2}}) + \sum(X_{s3})(EF_{X_{s3}}) \quad (2)$$

wherein S1 represents the direct emissions in $kgCO_2e$ L^{-1} within the set system boundary, X_{S1} and X_{S2} are energy consumption and material inputs to the system from different supply chain in kilogram per liter ethanol, respectively, and EF_{XS2} and EF_{XS3} are the emission factors of certain energy and material input in $kgCO_2e\ kg^{-1}$.

In carbon footprint accounting, especially of biofuels, if data on crop carbon pools and land-use change are not known, the carbon neutrality concept is being applied. In a nutshell, carbon neutrality of biofuels assumes that the carbon sequestered by the crop or the C stocks will eventually be emitted to the atmosphere. Therefore, all carbon emissions associated with the release of these C stocks (e.g., CO_2 produced from fermentation and bioethanol combustion as end-use) are not accounted in the carbon life cycle accounting.

Analysis of the process revealed that direct carbon emissions (S1) of the system are all relating to sugarcane c-stocks, therefore, materials and energy consumption of sugarcane farm and processing plant translated to kg material or energy per liter ethanol were of the main concern in data gathering from KII and FGDs. The data gathered were then validated through material balance analysis.

To standardize carbon life cycle inventory of the four bioethanol processing plants, the following yields and assumptions, which were obtained from surveys, KIIs and secondary data gathering, were used in the calculations:

- Average sugaracane yield in 2017 equivalent to 66.5 t ha^{-1} (SRA 2018)
- Truck and lorry capacity for hauling is 20 Mg with a fuel economy of 1.92 km L^{-1}
- Ship capacity for importation of fertilizers and chemicals is assumed to be 10,000 TEU with a mileage of 22.5 Mg d^{-1} and average speed of 22.5 knots
- Sugar yield in sugar mills is 2.05 L-kg Mg $cane^{-1}$ (*SRA 2018*)
- Distance of processing facility to farm is 20 km
- Distance of bioethanol facility to oil blending facility and gasoline stations is 120 km
- Molasses recovery in sugarcane stalks is 4% (S*RA 2018*)
- Bagasse recovery in sugarcane stalks is 36.08% (*SRA 2018*)
- Filter cake/mud press recovery in sugarcane stalks is 3.50%
- Ethanol yield from sugarcane stalks is 79 L Mg $cane^{-1}$ (average yield from bioethanol processing plants)
- Ethanol yield from molasses stalks is 245 L Mg $molasses^{-1}$
- Cogeneration yields are 86.21 kWh Mg $cane^{-1}$ and 2 kWh m^3 $molasses^{-1}$

To complete data as requirements to equation 2, GHG emission factors of materials and energy inputs were collated from literature review (**Table 3**).

GHG Emissions

Carbon Allocation. Bioethanol processing in the Philippines produces not only bioethanol but also liquid CO_2 (such as in the case of BPS 1 and 3), filter cake as fertilizer, as well as surplus electricity from cogeneration. Furthermore, molasses is a by-product of sugar milling of which the main product is sugar. Bagasse is also a by-product of sugar milling.

Given this multi-product scenario in the Philippines for bioethanol production, two-step economic allocation method was made. This means that the computed carbon footprint within the system boundary must not solely be attributed to bioethanol because there are other co-products and/or by-products that have economic values. Economic value is simply the quantity of products/co-products/by-products produced for a given amount of time multiplied to its present selling price. Then, a carbon allocation factor was computed based on the following formula:

$$CA_i = \frac{EV_i}{\sum_{i=1}^{n} EV_i} \quad (3)$$

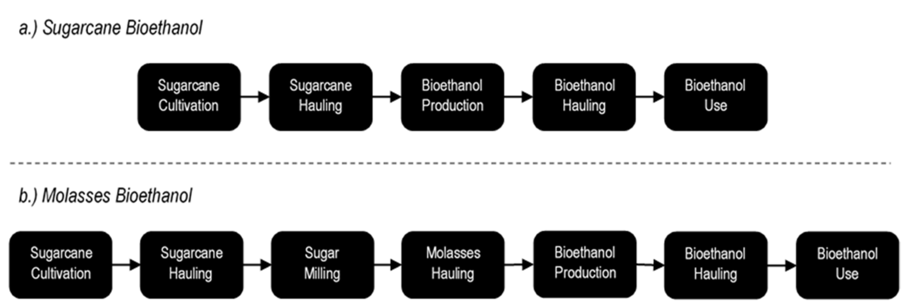

Figure 2. System boundary of environmental impact assessment study.

Table 3. List of GHG emission factors of the agro-chemicals, chemicals and energy inputs used within the study's system boundary.

Items	GHG Emission Factors ($gCO_2e\ kg^{-1}$)	GHG Emission Factors ($gCO_2e\ kg^{-1}$)
Agro-chemicals	Production Emissions	Field Emissions
Ammonium Phosphate (16-20-0)	730.00[1]	853.69[1]
Ammonium Sulphate (21% N, 24%S)	580.00[1]	1,084.90[1]
Urea (46-0-0)	910.00[1]	3,513.39[1]
Herbicide	25,500.00[2]	
Chemicals		
Lime	150.00[3]	
Hydrochloric Acid (HCl)	750.86[2]	
Caustic Soda (NaOH)	469.29[2]	
Sodium Chloride (NaCl)	200.00[3]	
Biocide	3,730.00[3]	
Sulfuric Acid (H_2SO_4)	207.73[2]	
Urea	910.00[3]	
Magnesium Sulfate ($MgSO_4$)	300.00[3]	
Lubricants, $gCO_2e\ L^{-1}$	947.00[2]	
Energy Inputs		
Diesel Fuel, $gCO_2e\ L^{-1}$	2,689.27[2]	
Electricity from Coal	1,938.89[4]	

[1] *Fertilizers Europe 2011*
[2] *Intelligent Energy Europe n.d.*
[3] *Winnipeg Canada Finance Department 2012*
[4] *Hong B.D. and E.R. Slatick 1994*

wherein CA is the carbon allocation factor for product *i*, EVi is the economic value of product *i*.

The first economic allocation was done after sugar milling, wherein the desired products is only molasses or both molasses and bagasse, depending on the feedstock requirement of bioethanol plant's cogeneration facility. The second economic allocation was done after bioethanol processing wherein liquid CO_2 and/or surplus electricity could be potential co-products depending on the cases of the four bioethanol plants being assessed.

Impact Assessment. Impact assessment of the calculated carbon life cycle inventory focused on the determination of hotspots along the system boundary through investigation of the individual components with relatively high GHG emissions and recommendations to reduce these hotspots, thereby maximizing the climate change mitigation potential of bioethanol. In addition, GHG emission reduction of bioethanol relative to a fossil fuel reference, expressed in percentage (%), was estimated and was used to project the GHG avoided by the Philippine bioethanol distillery over the span of 10 years (2009-2018). Equation 4 shows estimating the GHG emission reduction potential of bioethanol.

$$GHG\ Reduction\ (\%) = \frac{GWP_{fossil} - GWP_{bioethanol}}{GWP_{fossil}}\ X\ 100 \quad (4)$$

RESULTS AND DISCUSSIONS

Socio-economic Impact Assessment

Job Generation. One of the objectives of the Philippine biofuels law is to generate jobs and boost the country's rural economy. Therefore, evaluating job generation of the domestic bioethanol industry using the four bioethanol production systems as a case study is of prime importance.

The two sources of potential job generation in bioethanol production are from the cultivation of sugarcane crops at the farm, if the bioethanol plants use sugarcane as feedstock, and from the production of bioethanol at the processing plants.

For sugarcane cultivation, the job generations (in terms of man-days per hectare) estimated for BPS 1 and BPS 2 for new plant and ratoon at varying sizes (small or < or = 5 ha farms, and medium-to-large or > 5 ha farms) and types of operation (manual, mechanized or semi-mechanized) using the data gathered from FGDs (**Figure 3**). Note that BPS 1 and BPS 2 are the only production systems in the case study that uses sugarcane as feedstock.

In general, BPS 1 has higher jobs generated per hectare than BPS 2 while ratooning has lower job generation due to reduction in cultivation activities such

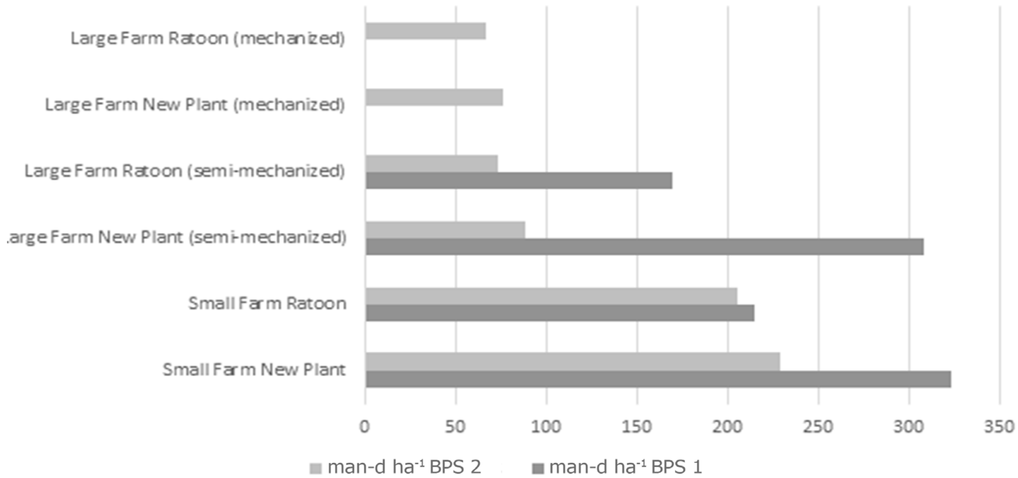

Figure 3. Job generation in sugarcane farms for bioethanol production.

as land preparation and planting. Furthermore, as expected, mechanization tends to lower job generation in sugarcane farm (**Figure 3**). Therefore, the highest estimated job generation is for small farm-new plant-manual of BPS 1 with 324 man-days ha^{-1}. Meanwhile, the lowest job generation calculated is 67 man-days ha^{-1} for BPS 2 large farm-ratoon-mechanized. This shows that size, mechanization and farm efficiency greatly affect the job generation of a sugarcane farm. But on the average, BPS1 new plant and ratoon have estimated job generation of 316 man-days ha^{-1} and 193 man-days ha^{-1}, respectively while BPS 2 new plant and ratoon have estimated job generation of 131 man-days ha^{-1} and 115 man-days ha^{-1}, respectively.

Moreover, results in **Figure 3** were used to determine the actual and potential annual job generations of BPS 1 and BPS 2. The actual annual job generations were drawn from the feedstock use data provided by these processing plants for the crop year (CY) 2017-2018. On the other hand, the potential annual job generations were based on the rated capacities of the sugarcane mills of the processing plants (**Figure 4**).

There is a huge additional job generation potential, if the two bioethanol processing plants use 100% sugarcane as feedstock to produce bioethanol (**Figure 3**). BPS 1 and BPS 2 are estimated to increase job generation associated with sugarcane cultivation by 18 and 4 times, respectively, for both ratoon and new plants.

Job generations of producing bioethanol in the processing plants of BPS 1, 2 and 3 were estimated based on KII (**Table 4**). Due to lack of data for BPS 4, job

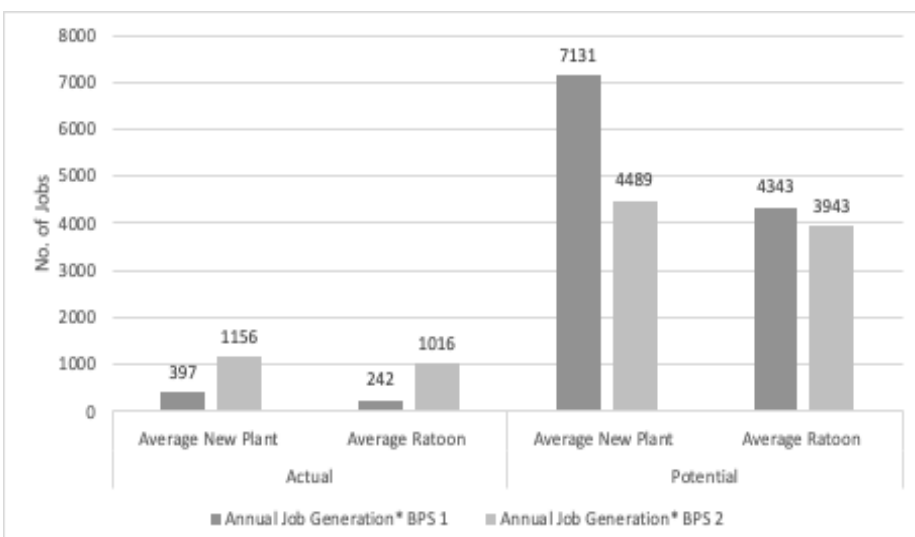

Figure 4. Annual job generations from sugarcane cultivation of BPS 1 and BPS 2 based on their actual feedstock use for CY 2017-2018 and their mill-rated capacity (potential).

Table 4. Job generation in bioethanol processing plants.

Processing Plant	Annual Job Generation
BPS1	299
BPS 2	153
BPS 3	215

generation estimation was not performed for this system.

In terms of the number of regular employees, BPS 1 has 159 regular employees with 102 rank and file, 115 casual workers, and 25 additional workers during off-season hired for the repairs and maintenance of the facility. This is compared to 101 regular employees and 52 casual workers from BPS 2 and 98 regular employees and 117 casual workers from BPS 3. Meanwhile, BPS 4 only provided a data of 100 casual workers for their processing plant.

Overall, BPS 1 ranked the highest in terms of the number of employees and workers combined at 299, BPS 3 was second at 215, and BPS 2 with 153. Based on these results, there were no observed trends in terms of the capacity of the bioethanol processing plant and type of feedstock being used.

It is also important to note that the four processing plants under study follow the provision of the labor code that 70% of the workers or employees must come from the locality. Moreover, it is common among the four processing plants to hire workers through an agency. This is to address the need to hire additional workers during the peak season.

In terms of age, the average for BPS 1 is 41 years old, with 20 years old being the youngest, and 63 years old being the eldest. On the other hand, BPS 3 has an average age of 37 years old, with 21 years old being the youngest and 59 being the eldest hired worker in the plant.

In the coming years, BPS 1 plans to reduce its manual labor needs due to facility improvements. This is also true for BPS 4 as it push for automation in the processing as well. On the other hand, BPS 3 wants to target an increase of 20% in terms of hiring female workers.

Adding the job generations of sugarcane plantation and bioethanol processing plant gives the total job generations of the three individual bioethanol production systems (BPS) and the grand total of three BPS (**Figure 5**).

Since BPS 3 only uses molasses for bioethanol, production its total job generation compared to the other two is lower (**Figure 5**). Furthermore, job generations of BPS 1 and 2 can increase considerably if the processing plants will utilize solely sugarcane. Therefore, in boosting the country's rural economy through increase in job generation, bioethanol from sugarcane is better than from molasses.

Perceived Impacts and Outcomes on the Economic and Lifestyle of Sugarcane Farmers. Significance of the perceived changes in the level of sufficiency of various household needs before and after the bioethanol distillery establishment were analyzed by conducting a test of proportion to surveyed farmers who cited sufficient level of each household needs indicator before and after the distillery establishment (**Tables 5** and **7**).

BPS 1 test of proportions of household needs at two time period (before and after) has produced statistically significant difference for all items. This implies a positive impact on the socioeconomic and lifestyle changes among BPS 1 sugarcane planters after the bioethanol

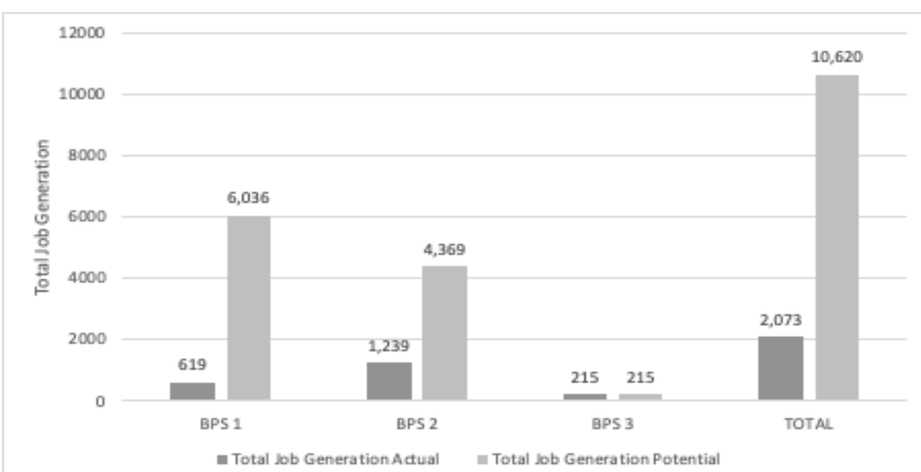

Figure 5. Total job generations of the bioethanol production systems.

distillery establishment in the area.

A statistically significant difference was indicated (1% level) in the proportion of BPS 2 sugarcane planters who have sufficient level for almost all their household needs (**Table 6**). These included food availability, clothing, health care, transportation, children's education, house construction, and agricultural inputs. The household need for the purchase of other assets was slightly significant at 10% level. These results imply that economic status and lifestyle of BPS 2 sugarcane planters have improved after the establishment of bioethanol distillery in the area.

Perceived Impacts on Employment and Income. Impact indicators, success and sustainability of the bioethanol distillery establishment are based, in large part, on stakeholders (e.g., farmers, traders, etc.) reactions to the industry. In turn, these reactions are based on stakeholders' perceptions of impacts, which are not always in accord with objective and quantifiable evidence (*Pomeroy et al. 1997*). It is therefore essential to understand perceptions of the present and future possible impacts of the bioethanol industry. Perception of impacts may explain some of the variance in the long-term, as well as short-term, success of the industry.

Table 5. BPS 1: Test of proportion for difference in the sufficiency of household needs among sugarcane planters before and after the distillery establishment.

Item	After		Before		Difference		z	P>|z|
	Mean	Std Error	Mean	Std Error	Mean	Std Error		
Food availability	1.000	0.000	0.789	0.066	0.211	0.066	3.063	0.002
Clothing	1.000	0.000	0.632	0.078	0.368	0.078	4.238	0.000
Health care	0.949	0.035	0.757	0.071	0.192	0.079	2.377	0.017
Transportation	0.950	0.034	0.622	0.080	0.328	0.087	3.548	0.000
Communication	0.946	0.037	0.500	0.086	0.446	0.093	4.024	0.000
Children's education	0.972	0.027	0.697	0.080	0.275	0.085	3.120	0.002
Purchase of land	0.724	0.083	0.417	0.101	0.307	0.130	2.261	0.024
Purchase of other assets	0.903	0.053	0.414	0.091	0.489	0.106	4.019	0.000
House construction	0.941	0.040	0.406	0.087	0.535	0.096	4.663	0.000
Agricultural inputs	0.939	0.042	0.600	0.089	0.339	0.099	3.236	0.001

Table 6. BPS2: Test of proportion for difference in the sufficiency of household needs of sugarcane planters before and after the distillery establishment.

Item	After		Before		Difference		z	P>|z|
	Mean	Std Error	Mean	Std Error	Mean	Std Error		
Food availability	1.000	0.000	0.767	0.077	0.233	0.077	2.900	0.004
Clothing	1.000	0.000	0.774	0.075	0.226	0.075	2.851	0.004
Health care	1.000	0.000	0.774	0.075	0.226	0.075	2.851	0.004
Transportation	0.968	0.032	0.677	0.084	0.290	0.090	2.992	0.003
Communication	0.900	0.055	0.774	0.075	0.126	0.093	1.327	0.185
Children's education	1.000	0.000	0.821	0.072	0.179	0.072	2.342	0.019
Purchase of land	0.767	0.077	0.586	0.091	0.180	0.120	1.483	0.138
Purchase of other assets	0.897	0.057	0.724	0.083	0.172	0.100	1.675	0.094
House construction	0.806	0.071	0.467	0.091	0.340	0.115	2.763	0.006
Agricultural inputs	0.968	0.032	0.621	0.090	0.347	0.096	3.358	0.001

Table 7. BPS 2: Perceived impacts on the changes in employment opportunities and income among sugarcane farmers.

Impact Indicator	After		Before		Difference		t-value	p
	Mean	SD	Mean	SD	Mean	SD		
Employment (t2-t1)	6.59	1.92	4.78	2.71	1.81	2.66	3.859	0.0005
Employment (t3-t2)	7.70	2.20	6.57	1.98	1.13	1.89	3.286	0.0027
Cash income from bioethanol related operations (t2-t1)	6.81	2.02	5.03	2.56	1.77	2.53	3.91	0.0005
Cash income from bioethanol related operations (t3-t2)	7.77	2.39	6.73	2.02	1.03	1.79	3.16	0.0037

In this study, impact indicators assessed using self-anchoring ladder-like scale with 10 steps are as follows: Employment opportunities, and cash income from bioethanol-related operations (*Di Napoli and Arcidiacono 2013*). The respondents were told that the first step represents the worst possible situation while the highest step could be described as the best possible outcome. The respondents would then be asked where the situation was before the bioethanol distillery, where it is at present, and where he/she believes it will be 5 years in the future. Note that this assessment was done only in the BPS 2 study site.

A paired comparison t-test was conducted to determine whether the mean differences between the two time periods are statistically significant (**Table 7**). A statistically significant increase in perceived level for both employment opportunities and cash income. These findings strengthen further the impacts of the bioethanol industry to the sugarcane farmers and the community in general.

Since the study has not implemented the ladder-like diagram method of assessing perceived impacts in BPS 1 study site, a few other proxy indicators were assessed before and after bioethanol distillery establishment. The proxy indicators are as follows: total cost of production per hectare; cane yield (Mg ha^{-1}); and number of laborers per ha employed in the farm. A paired comparison t-test was calculated to determine whether the mean differences between two time periods are statistically significant.

The average cane yield has increased significantly from 48 Mg ha^{-1} a^{-1} before to 61 Mg ha^{-1} a^{-1} after the bioethanol distillery was established. Likewise, the total cost of production in nominal terms has slightly increased from PhP 37,172 ha^{-1} (USD 743.44 ha^{-1}) to PhP 43,698 ha^{-1} (USD 873.96 ha^{-1}) after the establishment of bioethanol distillery, although it is not statistically significant (**Table 8**). The increase could be attributed to inflation and not in real value. The number of laborers employed in the farm before and after the establishment of bioethanol distillery did not show statistically significant difference. It means production practices have changed but laborers in the farms were kept at the same level.

Socio-economic impact assessment study in Brazil also revealed that positive socio-economic benefits are experienced in areas where sugarcane bioethanol production is located (*Walter et al. 2011*).

Lastly, additional revenues of industries related to bioethanol production were estimated using the data gathered from KII and administrative data. The estimated total additional revenues of bioethanol related-industries from the actual data in CY 2017-2018 of the four bioethanol production system under study is PhP 1.20 B (23.9 M USD) while the calculated potential total additional revenues if BPS 1 and BPS2's rated installed milling capacity and electricity generation will be achieved is PhP 3.02 B (60.4 M USD). Contributions of sugarcane amounted to 71% to the total revenues in these bioethanol-related industries (**Figure 6**).

The sugar milling industry has the highest revenue generation or 63% of the total combined revenues of the six short-listed bioethanol-related industries (**Figure 6 a**). This is because of the calculated historical statistical price increase of molasses of about PhP 2,104 Mg-molasses^{-1} (USD 42.08 Mg-molasses^{-1}). Generated liquid CO_2 from bioethanol also provides huge revenue not only to the processing plant but to the overall liquid CO_2 industry in

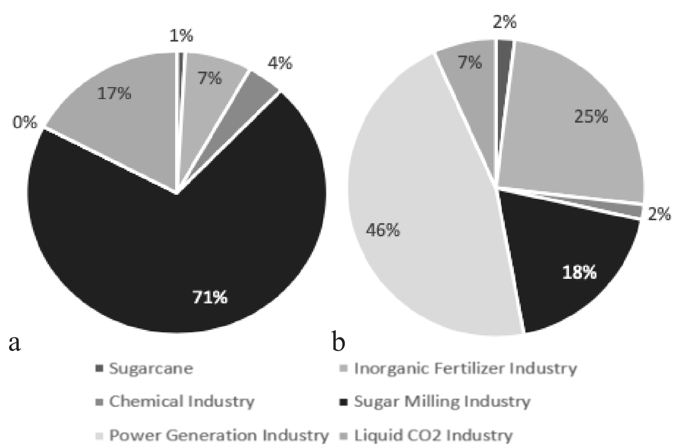

Figure 6. Revenue contributions (in %) of industries related to bioethanol production as a result of the bioethanol program for CY 2017-2018, a) based on actual data vs. b) potential.

Table 8. BPS 1: Perceived impacts on the changes in employment opportunities and income among sugarcane farmers.

Impact Indicator	After		Before		Difference		t-value	p
	Mean	SD	Mean	SD	Mean	SD		
Total cost of production (PhP ha^{-1})	43,697.92	31,565.87	37,171.88	21,420.75	6,526.04	18,263.75	2.0213	0.0520
Average cane yield (Mg ha^{-1}a^{-1})	61.28	23.78	47.96	18.70	13.32	24.07	3.1304	0.0038
No. of laborers per hectare	9.39	4.87	9.81	4.89	-0.43	5.53	-0.4589	0.6493

1 US$ = PhP 50.00

the country. On the other hand, if the rated electricity generation capacity of BPS 1 and BPS 2 are achieved, additional revenues to the power generation industry gives the largest revenue among the other industries (**Figure 6b**). Also, the revenue of inorganic fertilizer is expected to increase due to the increase of sugarcane plantations to cater the rated milling capacity of both BPS 1 and BPS 2, respectively. Meanwhile, revenue associated with increase in molasses price decreases significantly in terms of its percentage to the total revenue generation, or a slight decrease to the total additional revenue of sugar mills from PhP 844 M to PhP 560 M. (USD 11.20 M). Similar study suggests that sugarcane-ethanol sector in Brazil has a value-addition of about PhP 140 B (USD 2.8 B) (*Martinez et al. 2013*) being the largest producer of ethanol in the world.

It is also significant to mention that bioethanol processing in the Philippines, specifically in the case of BPS 1 and BPS 2, can replace a portion of inorganic fertilizer use. Treated spent wash from the distillery can be used as organic fertilizer to the sugarcane farms.

Environmental Impact Assessment

Global Warming Potential (GWP) and GHG Emission Reduction Potential of Bioethanol Production in the Philippines. From carbon life cycle inventories, GWPs or carbon footprints of the four domestic bioethanol production system scenarios were determined and summarized (**Table 9**).

It can be observed that BPS 1 has the lowest carbon footprint, and therefore has the highest GHG emission reduction potential, followed by BPS 3, BPS 4, and BPS 2 (**Table 9**). Compared to the average GHG emission reduction of sugarcane bioethanol in Europe of 71% (*Intelligent Energy Europe n.d.*), BPS 1, 2 and 3 have higher GHG emission reduction potentials. In terms of bioethanol carbon footprint comparison with other countries, life cycle assessment of fuel ethanol in Argentina suggests that sugarcane ethanol emits 15.0 kg CO_2e kg ethanol^{-1} (or 12.0 kg CO_2e L^{-1}) while molasses ethanol emits 22.0 kg CO_2e kg^{-1} (or 18.0 kg CO_2e L^{-1}) (*Amores et al. 2013*) which is significantly large compared to the carbon footprint of bioethanol in the Philippines calculated in this study. Moreover, sugarcane ethanol carbon footprint in Mexico (*Garcia et al. 2011*) is 36.8 kg CO_2e GJ ethanol^{-1} (or 0.78 kg CO_2e L^{-1}) while that from Brazil (*Macedo et al. 2008*) is 27.5 kg CO_2e GJ^{-1} (or 0.583 kg CO_2e L^{-1}). Molasses bioethanol carbon footprint, on the other hand, in Iran has a carbon footprint of 1.32 kg CO_2e L^{-1} (*Farhani and Asoodar 2017*).

Table 9. Carbon footprints of bioethanol from four different processing plants and their respective GHG emission reduction equivalents.

Bioethanol Plant	Bioethanol Carbon Footprint	GHG Emission Reduction
	kgCO_2e L^{-1}	%
BPS 1	0.25	90.83%
BPS 2	0.49	81.82%
BPS 3	0.66	75.45%
BPS 4	0.84	68.92%

To investigate the differences among the four bioethanol plants, This study presented the carbon footprints of major units contributing to the total carbon footprint of a given bioethanol processing system within the defined system boundary (**Figure 7**).

There were huge carbon footprint variations of major components of the four domestic BPS under study (**Figure 7**). However, it is obvious that feedstocks have the highest carbon footprint contribution among the different major components of Philippine bioethanol production. For BPS 1 and BPS 2 which utilize both sugarcane and molasses as feedstocks for bioethanol production, calculated carbon footprints are directly related to the % share of these feedstocks to yield their annual bioethanol production. Hence, BPS 1 has higher carbon footprint attributed to molasses than sugarcane because 94% of their feedstock requirement in CY 2017-2018 was from molasses; the remaining 6% feedstock requirement is supplied by sugarcane stalks. Meanwhile, BPS 2 uses 77% sugarcane and 23% molasses resulting to higher carbon footprints attributed to sugarcane plantation.

Carbon footprint of molasses as feedstock in bioethanol processing plant was computed by projecting the sugarcane stalks requirement and hectarage to produce the required volume of molasses of the plant. In the Philippines, molasses is typically obtained from sugar mills as it is a by-product of sugar crystal production. Therefore, carbon footprint of molasses can be broken down to sugarcane cultivation in the field, transportation of the sugarcane stalks to sugar mill, sugar milling yielding molasses as by-product as well as transportation of filter cake as another by-product of the process to its market. Note that since sugar milling yields multiple products allocation method was applied.

On another hand, for BPS that uses solely molasses or does not have enough bagasse to supply its plant power requirement, additional bagasse requirement carbon

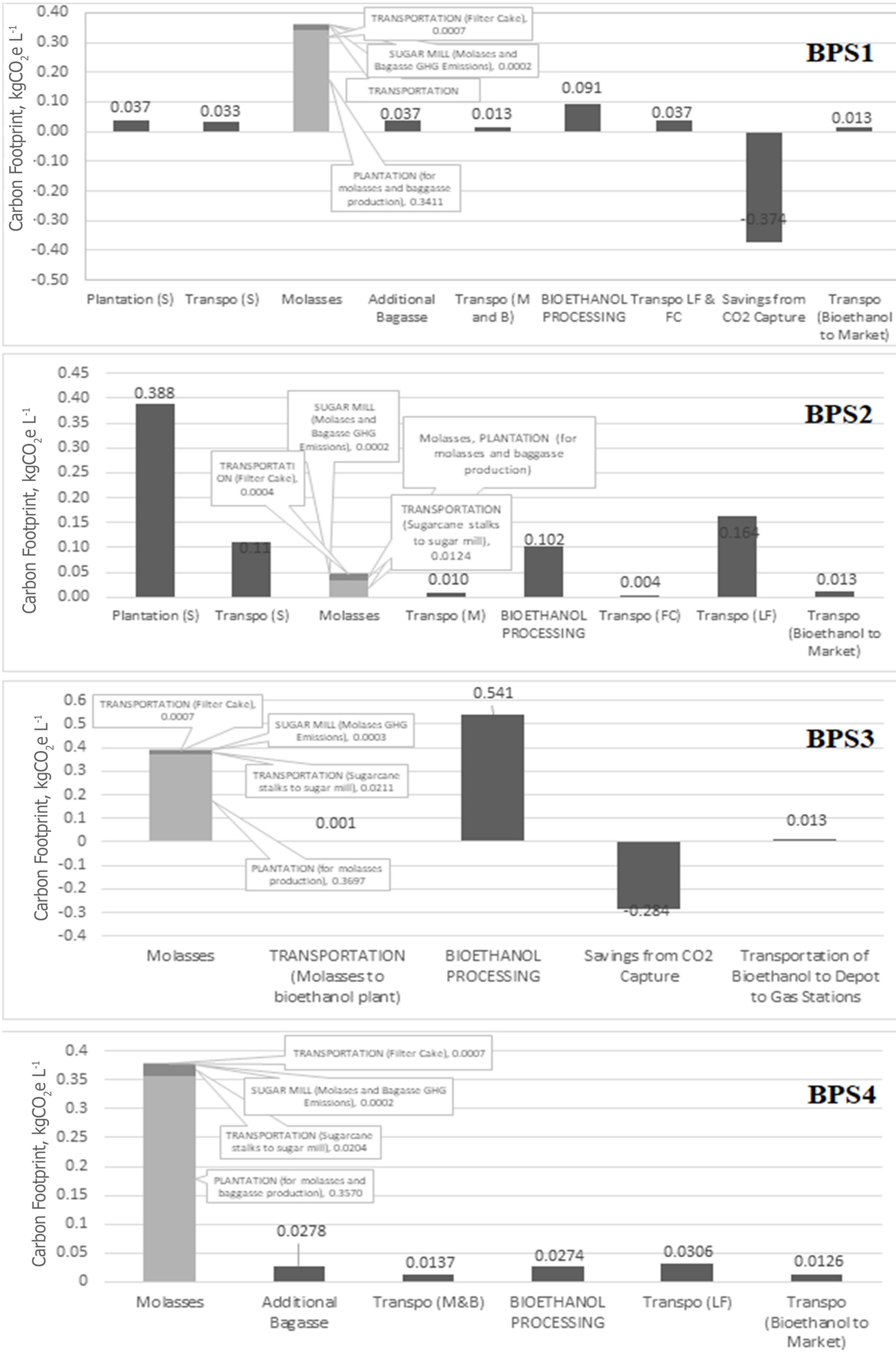

Figure 7. Carbon footprints of major components of the four bioethanol production systems (BPS) under study (S = sugarcane, M=molasses, B=bagasse, FC=filter cake, LF= Liquid Fertilizer).

footprints were compute except for BPS 3 which uses coal instead of bagasse. The coal use of BPS 3 instead of bagasse resulted to the highest bioethanol processing carbon footprint among the four BPS under study. The carbon savings from CO_2 capture of BPS 3 significantly reduces its total carbon footprint. Likewise, carbon capture savings of BPS 1 further reduces its total carbon footprint.

For BPS 1, 3 and 4, bioethanol production has the second largest carbon footprint next to feedstocks due to chemical and energy requirements of the bioethanol plant. But then for BPS 2, transportation of feedstocks and products comes as second. This is because the average distance of sugarcane farm to the processing plant is four times larger than that of the other BPS.

Both BPS1 and BPS 2 can further reduce its carbon footprint and increase its GHG emission reduction potential if they maximize their power production equivalent to its rated installed capacity which would result to surplus electricity that can be sold to the grid. Based on the carbon intensity of electricity in the country, carbon savings from surplus electricity is about 534 $gCO_2e\ kWh^{-1}$ (*IPCC 2005*).

Estimated GHG emission reduction of the Philippine bioethanol industry from 2009-2018. Based on the actual annual domestic bioethanol supply from DOE from 2009 to 2018, the annual GHG emission reductions were estimated based on the average avoided GHG emissions of 2.14 $kgCO_2e\ L^{-1}$ calculated from the four BPS under study. The annual GHG emissions avoided was 2,540 Gg CO_2e from 2009 to 2018 (**Figure 8**). The GHG emissions avoided only consider the actual local bioethanol supply and doesnot account the possible GHG emissions avoided from bioethanol importation (**Figure 8**).

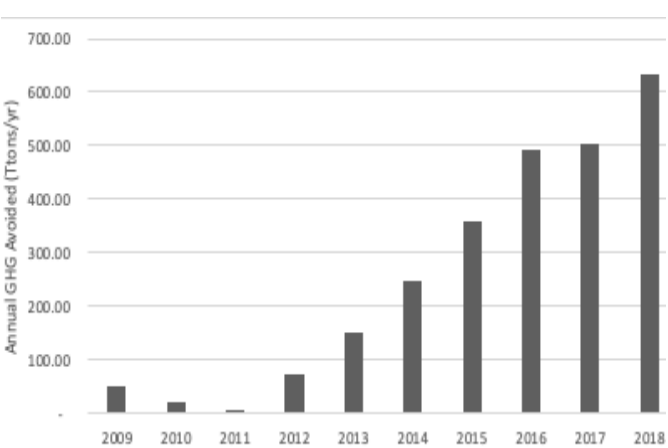

Figure 8. GHG emissions avoided of the Philippine bioethanol program from 2009 to 2016.

The annual GHG avoided is directly proportional to the domestic bioethanol supply, higher domestic bioethanol supply means higher GHG reductions for the country (**Figure 8**).

CONCLUSIONS AND RECOMMENDATIONS

The success and sustainability of the bioethanol industry depend largely on its socioeconomic and environmental impacts to different stakeholders. The results of the socio-economic impacts confirmed that the bioethanol distillery has generated significant job in the community. For the sugarcane farmers, the industry was perceived to have a positive change in employment opportunities and cash income from bioethanol-related operations.

Environmental impact assessment study, on the other hand, revealed that domestic bioethanol production can reduce GHG emissions by about 65 to 88%, compared to business-as-usual scenario of using fossil fuel.

Based on the findings of the study, several strategies and policy recommendations are suggested towards a more sustainable bioethanol production in order to sustain the success of the industry. These recommendations include: increase sugarcane production area; intensify research and development on high-yielding sugarcane variety; establish crop insurance policy for sugarcane crops; promote sugarcane industry stakeholders capacity building particularly on sugarcane planters' trainings on sugarcane cultural management, early warning systems (EWS), livelihood and financial literacy, and on establishing linkages with government and private institutions for government program awareness and access to credits, and lastly; and encourage "zero-waste" bioethanol production system that promotes additional revenue and carbon savings for the processors. Optimization of sugarcane biorefinery technologies in Brazil conducted by *Cavalett et al.* (*2011*) resulted in decreased environmental footprints and improved economic impacts.

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