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Sugarcane Bioethanol Processing Plant in the Philippines: Energetics and Water Inventory

ABSTRACT

Biofuels production is intended to address shortage on fuel supply. This study assessed the energetics and water inventory of the Philippine bioethanol production from sugarcane, aiming to provide a definitive value from where studies for economic assessment for this system could pick up. A 30-million-liter-per-year (MLPY) processing facility was designed using local field and factory data, from surveys and immersion reports. Assessment showed that sugarcane bioethanol processing facility with co-generation and wastewater treatment units gains a net energy equivalent to 18.62 MJ L^{-1} of bioethanol produced, with an energy returned on energy invested ratio of 2.75. The net energy realized from the production compensates the energy expended during the construction of the bioethanol plant within about eight months of operation. Water is being used up at a rate of 2,832.22 L per L of ethanol produced or 133.60 L per MJ or 197,826.09 L per Mg of cane processed, accounting the water used for plantation and the factory. The water inventory in the construction level amounts to 952.64 ML. The production of bioethanol from sugarcane is practical, energy-wise, but its water consumption might make the industry unviable in locations where water is scarce.

Keywords: *energetics, energy, water inventory, water consumption, requirement, bioethanol, sugarcane, Philippines*

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INTRODUCTION

During the earlier times, attention to biofuel production was predominantly motivated to address shortage in fuel supply (*Kolb 2014*). Discoveries of huge petroleum reserves have delayed progress for these renewable fuels (*National Geographic 2015*). However, due to oil price hikes and increase in the global consciousness about climate change caused by pollution, it has been sensed that greater actions towards greener practices should be promoted. Biofuels have regained evolvement and the development of feedstock for biofuels production has attracted attention for research.

Molasses, a by-product of the sugar production from sugarcane, is the primary feedstock utilized for bioethanol production in the Philippines. This is due to the existing Joint Administrative Order (JAO) No. 2008-1, Series of 2008, which prohibits the use of agricultural areas for biofuel feedstock production. Sugarcane feedstock can be used if the areas planted, as evaluated by the Department of Agriculture, is underutilized and marginal. However, the Sugar Regulatory Administration (SRA) revealed that there is a surplus in the domestic production of sugar considering the regular demand for local consumption and export (*SRA 2015*). If the JAO could be amended, the excess in sugar could be used to increase domestic production of bioethanol, which currently only accounts for about half of the total demand for a 10% ethanol blending (E10) to gasoline (*DOE 2017*). Sugarcane with high sugar content is a very desirable feedstock to produce products at a competitive price. The sugar industry can opt to produce raw sugar, power, and/or bioethanol at the same time, which makes it a very flexible investment.

Local investments on bioethanol plant are supported by the Biofuels Act of 2006 (Republic Act 9367), which establishes that blends of gasoline and bioethanol are mandatory. By increasing this blend, the increase in the demand for bioethanol can be projected. Together with this anticipation, investment in the area is incentivized, which should attract more developers. The Act mainly aims to reduce dependence on imported oil and be energy self-sufficient, and to significantly reduce greenhouse gas (GHG) emissions generated with the use of fossil fuels. Bioethanol production from sugarcane has already been proven to be carbon negative, considering the sequestration capabilities of the plant (*Demafelis et al. 2017; Lisboa et al. 2011*). However, aside from these primary objectives, the viability of producing these greener alternatives should also be evaluated in terms of net energy consumption, economic competitiveness, and reproducibility (*Hill et al. 2006*).

Energy crops can deliver energy demands and are economical and environmentally beneficial (*Koçar and Civaş 2013*). This study focuses on the energetics of bioethanol production from sugarcane, following the farm practices and factory operations in the Philippines. Water inventory was included since it can be derived from the methodology of the energy assessment. Currently, the country already utilizes about 80% of its water supply for agriculture. Water supply seasonality is also experienced due to the country's dry season (*Inocencio et al. 2018*). Fuels crops are said to require large quantities of water (*Gerbens-Leenes and Hoekstra 2011*), hence quantifying the water needed for its production is also a critical measure for its sustainability.

MATERIALS AND METHODS

The system boundary of the energy and water inventory expands from cradle to grave. It involved the feedstock production in the plantation, the bioethanol production in the facility, and the distribution and use of the end-products. The inventory summed up the expended and produced energy, and water consumed from the pre-operation period or the construction of the factory, the production of the feedstock, the operations period, and the end-use of the products (**Figure 1**).

Firstly, a material balance was carried out to account for the materials to be used to produce 30-MLPY bioethanol. The energy balance was calculated and the equipment involved in the whole operation were sized; their operational parameters, specifications, and costs were also collected. The plant layout was carried out, including pipes and pumps. Final values are reported as amount of energy expended per volume of biofuel produced, amount of energy gained per volume of biofuel produced, and amount of water expended per weight of cane processed and per volume and per energy of biofuel produced. These data should allow venture capitalists to estimate profitability in producing bioethanol from sugarcane within the specified conditions.

Construction

The pre-operation inventory included the energy used in the fabrication of equipment and construction of facilities. It also included transport of materials for the construction, which in this case, was assumed to come from 150-km distance. Materials were transported using heavy-duty trucks with hauling capacity of 10 Mg and fuel economy of 2.126 km L^{-1} diesel obtained from the Greenhouse Gases, Regulated Emissions and Energy

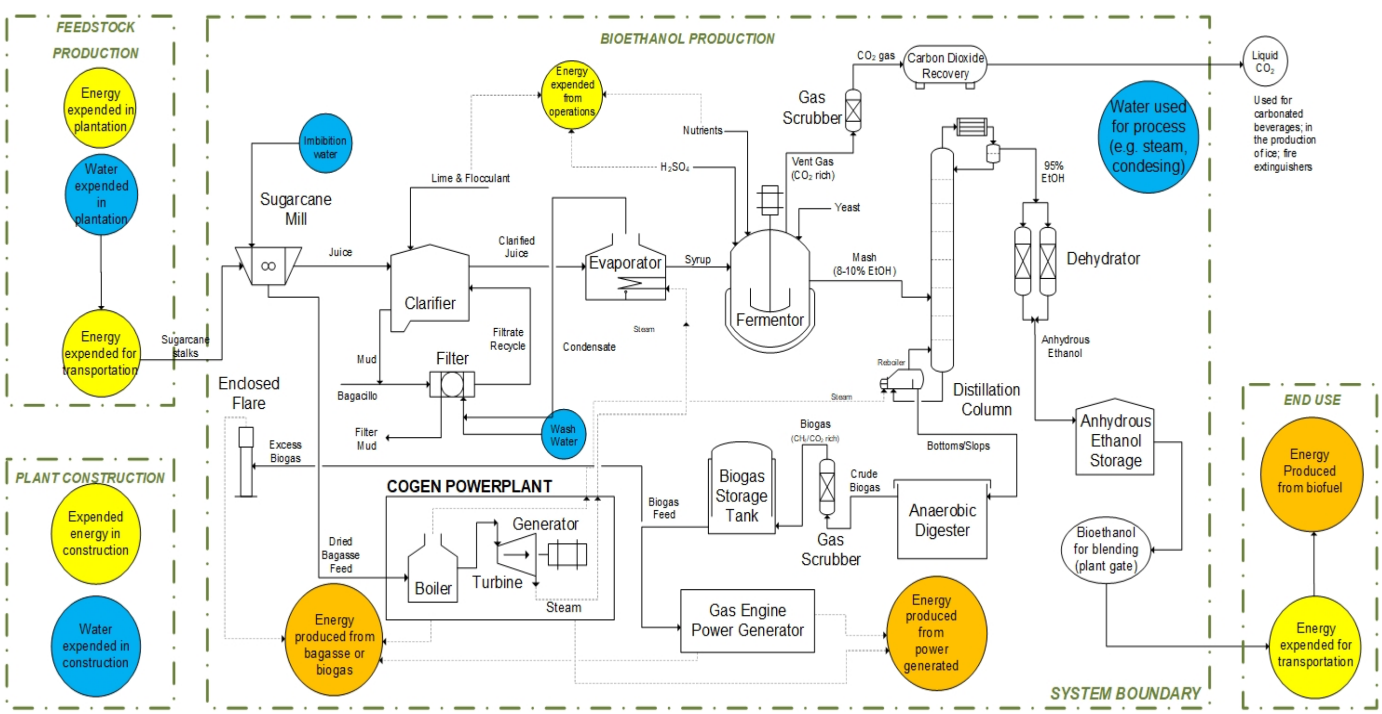

Figure 1. Process flow diagram of bioethanol production from sugarcane and the energetics and water inventory sources in the construction, the farm, the facility and end-use.

Use in Transportation (GREET) 2013 (*Argonne National Laboratory 2013*). The total energetic expenses were accounted as debt and were used for the "payback period" computation, which will be discussed later in this section. The energy factors used for the materials were obtained from the Inventory of Carbon and Energy (ICE) version 2.0 by *Hammond and Jones* (*2011*).

During the production of ethanol, all the energy expended in the process were accounted and subtracted from the total energy equivalent that could be harnessed from the products – bioethanol and power produced from bagasse and biogas, to get the "net energy gain" (NEG). The inventory considered the "embodied energy" or the energy consumed in the overall manufacture of the raw materials and the total power consumption of the whole operation. The equivalent energy for the material inputs were obtained from GREET 2014 (*Argonne National Laboratory 2014*).

The water inventory, conversely, considered the total volume of water consumed. The inventory was divided into two: the footprint of the construction and the footprint of the production. The footprint of the construction considered the embedded water of the construction materials. The values used were 40,000 L Mg^{-1} steel (in this paper, also applied for stainless steel and galvanized sheet) and 2,000 L Mg^{-1} concrete (also applied for gravel) (*Zygmunt 2007*). The footprint in the production is the summation of water consumption computed from the material balance.

Farm

The farm data used in this study came from actual field survey in Batangas, Philippines, specifically from Batangas Integrated Sugarcane Planters Multipurpose Cooperative (BISPMC) by *Mendoza* (*2005*). The plantation uses 10 kg sugarcane seeds per hectare, which allows a sugarcane harvest of 65 Mg ha^{-1} yr^{-1}. A total plantation area of 6,607.72 ha was needed to supply enough feedstock to the factory running at a daily capacity of 1,533.94 Mg cane.

The canes collected from the field were then stacked and transported using a heavy-duty truck with a hauling capacity of 10 Mg and fuel economy of 2.126 km L^{-1} diesel (*Argonne National Laboratory 2013*). The plantation was assumed to be 50 km away from the factory.

Factory

As no single local private firm will divulge their detailed investment for their respective facilities, the authors used the available production data to produce a detailed engineering design of a sugarcane bioethanol facility. It is a combination of several existing local processing plants, using representative actual values for each process. Most of the figures used for computation of the material balance were obtained from an existing sugar factory in Negros Occidental, Philippines. The general production processes were designed after several local practicum reports from Batangas, Cagayan, and Davao, and actual field experience.

First, the delivery trucks were weighed at the entrance of the factory to quantify the feed available. The canes were then immediately dumped to the start of the process for pre-treatment before milling. The biomass was then delivered to the mills through carriers and passed through a leveler, two cane cutters, and one shredder before the extraction mills. The design considered a four-mill tandem that had a pol extraction efficiency of 92.5%. The juice from the extraction went through clarification by hot liming. The clarified juice produced was evaporated (quadruple-effect) to achieve a syrup at 65°Brix.

The concentrated syrup was then diluted to 18°Brix, which is ideal for promoting yeast activity for fermentation (*Johnson and Seebaluck 2013*). The diluted syrup was fermented by adding yeast (*Saccharomyces cerivisiae*), after which, the sugar was converted to ethanol for 24-30 hours. The CO_2 released in the reaction was collected through the CO_2 recovery facility, while the yeast was recovered by centrifugation at 80% (w/w yeast) efficiency. The components of the produced ethanol mixture were separated via distillation, which produces 95-96% (v/v) hydrous ethanol. After the separation, the impure mixture of ethanol and water was fed to a molecular sieve to obtain 99.94% purity. Wastewater drained through the bottom of the distillation column. This was treated in an anaerobic digester, generating biogas and was further treated in facultative lagoon.

The design of the factory also incorporated a co-generation facility, which utilizes bagasse as fuel for boiler. The bagasse has a heating value of 8,784.6 kJ kg^{-1} (*Jayes 2019*) and the designed boiler operates at 6.7 MPa and 510°C.

The factory operates for 280 d yr^{-1}, and 24 hr d^{-1}. Final values were reported by amount of energy expended per volume of biofuel produced, amount of energy gained per volume of biofuel produced, and amount of water expended per volume and per energy of biofuel produced.

Payback Period

The payback period is the length of time it takes to compensate the amount expended in the pre-operational period. It was computed by dividing the total amount of energy expended from the pre-operations period by the NEG.

The construction, field and factory operations in sugarcane bioethanol production have respective energy factors/embodied energy used (**Table 1**).

RESULTS AND DISCUSSIONS

The assessment was conducted with the basic aim of quantifying the net energy harnessed from the products of the whole industry of ethanol production from sugarcane and its corresponding water requirement. A positive energy gain is desired in order to affirm the viability of the system. The paper also presents the energy payback period, considering the energy expended during the construction of the facility.

Energetics in the Construction

The first part of the assessment was the construction of the facility and the fabrication of equipment. The largest amount of energy is expended in the construction of miscellaneous area in the factory, such as the administration building, canteen, clinic, fire station, laboratory, and warehouse/workshop area with 29.03% (135,852,411.13 MJ) of the total, which is 467,901,597.45 MJ. This is followed by the energy used for material transportation with 23.27% (108,878,562.44 MJ); the construction of auxiliary process facilities with 16.26% (76,080,345.51 MJ); the wastewater treatment facility with 16.15% (75,544,074.10 MJ); fermentation, distillation and CO_2 recovery facility with 8.48% (39,663,695.95 MJ); co-generation facility with 4.66% (21,782,921.38 MJ) and pre-treatment facility that includes milling and evaporation with 2.16% (10,099,586.94 MJ) (**Table 2**).

Energetics in the Field

In this part, all the energy expended in the field level

Table 1. Energy factors used in sugarcane bioethanol facility construction, sugarcane plantation and factory operations in the Philippines.

Item	Energy Factor	Reference
Construction	**MJ kg^{-1}**	
Stainless Steel	56.7	ICE v. 2.0
Concrete	1.11	ICE v. 2.0
Steel	20.1	ICE v. 2.0
Concrete Block (Hollow Block)	0.81	ICE v. 2.0
Cement Mortar (1:3)	1.33	ICE v. 2.0
Cement (General-Typical)	4.6	ICE v. 2.0
Sand (dry, ρ=1602 kg/m^3)	0.005	ICE v. 2.0
Gravel (dry, ρ=1362 kg/m^3)	0.017	ICE v. 2.0
Galvanized Iron Sheet	22.6	ICE v. 2.0
Field		
Sugarcane seeds (MJ kg^{-1})	0.02	*BioGrace 2013*
Fertilizer utilization MJ kg^{-1}		
P_2O_5	22.19	*GREET 2014*
K_2O	9.02	*GREET 2014*
Nitrogen	62.96	*GREET 2014*
Lime	5.37	*GREET 2014*
Herbicide	276.59	*GREET 2014*
Insecticide	327.32	*GREET 2014*
Diesel Consumption MJ L^{-1}	43.41	*GREET 2014*
Factory[2] MJ kg^{-1}		
Lime (Calcium oxide, CaO) from clarification	5.37	*GREET 2014*
Sulfuric Acid (H_2SO_4) from fermentation	0.65	*GREET 2014*
MgSO4	8.28	*GREET 2014*
Urea	31.89	*GREET 2014*
Di-Ammonium Phosphate (DAP) from fermentation	19.16	*GREET 2014*
Biocide	120.00	*Moghimi et al. 2014*
Yeast (*Saccharomyces cerivisiae*)	43.00	*GREET 2014*

Table 2. Energetic expenses in the construction of the 30-MLPY sugarcane bioethanol facility and the fabrication of equipment.

Source	Energy Debt (MJ)	Percentage (%)
Fermentation, Distillation and CO_2 Recovery Facility	39,663,695.95	8.48
Pre-treatment Facility (Milling & Evaporation)	10,099,586.94	2.16
Power Plant	21,782,921.38	4.66
Wastewater Treatment Facility	75,544,074.10	16.15
Auxiliaries	76,080,345.51	16.26
Miscellaneous	135,852,411.13	29.03
Transportation	108,878,562.44	23.27
Total	467,901,597.45	100.00

were registered, including cane seeds production, fertilizer utilization, herbicide, insecticide, and diesel consumption of different machineries and other activities. The energy inputs in the 6,607.72 ha plantation was calculated from the material balance, presented in MJ yr^{-1} (**Table 3**).

The biggest contribution of the total energy expended in the field was due to the addition of quick-lime, which constitutes to 46.51% of the total energy expenditures (70,997,946.64 of 152,641,509.28 MJ). The lime is essential because it significantly improves the fertilizers efficiency and increases the production at a lower cost. Since the soil in humid areas such as in Philippines is commonly acidic, the lime acts as a neutralizer of soil pH, which results to increased availability of major nutrients needed by plants (*Choudhry 1984*). It is followed by fertilizer utilization at 31.34% (47,842,136.67 MJ) (Nitrogen at 13.08%, P_2O_5 at 12.87%, and K_2O at 5.39%). The rest follows at 19.28% by the total diesel consumption in the operation (29,433,230.98 MJ yr^{-1}); 2.63% for herbicide, 0.23% for insecticide application; and an almost negligible fraction for the sugarcane seed usage.

The harvested sugarcane is then transported to the factory, which consumes a total of 43,860,032.42 MJ yr^{-1} (due to diesel consumption).

Energetics in the Factory

The sources of energy in the factory are due to the manufacture of materials used to carry out the operations in liming and fermentation, and from the total power consumed in the process (**Table 4**).

With a milling capacity of 1,533.94 Mg d^{-1} cane, the factory was rated at 4.71 MW, which equated to 114,048,785.80 MJ yr^{-1}, contributing to the 97.62% of the total energy expenditures in the factory level (116,835,162.61 MJ yr^{-1}). It is insignificantly followed by the contributions from the chemicals for liming: lime at 0.99%; and for fermentation: urea at 1.26%; diammonium phosphate at 0.38%; biocide at 0.32%; sulfuric acid at 0.31%; magnesium sulfate at 0.08%; and yeast (Saccharomyces cerivisiae) at 0.05%.

The filter mud accumulated from the operation was delivered in a composting facility, assumed to be 8 km away from the factory, consumes diesel and contributes to the expenditures with 263,160.19 MJ yr^{-1}. The bioethanol produced was also delivered to the blending facility which was assumed to be 150 km away, contributing to the expenditures by 4,595,324.81MJ yr^{-1}.

Table 3. Energy contribution of the activities in the sugarcane plantation.

Item	Amount	Energy expended (MJ a^{-1})	Percentage
Sugarcane seeds, kg ha^{-1}	10	1,321.54	0.00
Fertilizer utilization, kg ha^{-1}			31.34
P_2O_5	134	19,644,975.83	12.87
K_2O	138	8,229,005.42	5.39
Nitrogen	48	19,968,155.43	13.08
Lime, Mg ha^{-1}	2	70,997,946.64	46.51
Herbicide, kg ha^{-1}	2.2	4,020,814.73	2.63
Insecticide, kg ha^{-1}	0.16	346,058.71	0.23
Diesel Consumption			
Plant cane, L ha^{-1}	102.6	29,433,230.98	19.28
Total		152,641,509.28	100.00

Table 4. Energy contribution from material inputs and electricity use in the sugarcane bioethanol facility.

Item	Amount (kg yr^{-1})	Energy expended (MJ yr^{-1})	Percentage
Lime (Calcium oxide, CaO)	214,751.03	1,153,716.63	0.99
Sulfuric Acid (H_2SO_4)	558,181.92	363,133.29	0.31
$MgSO_4$	10,734.27	88,926.30	0.08
Urea	46,004.00	1,466,860.94	1.26
Di-Ammonium Phosphate (DAP)	23,002.00	440,810.50	0.38
Biocide	3,066.93	368,032.04	0.32
Yeast (Saccharomyces cerivisiae)	1,363.09	58,613.74	0.05
Electricity Use, MWh a^{-1}	31,680.22	114,048,785.80	97.62
Total		116,835,162.61	100.00

Net Energy Gain

To calculate net energy from the energy balance, the products of the process – power (from bagasse and biogas) and ethanol are converted to energy equivalent (**Table 5**).

The 30-MLPY bioethanol production was equivalent to 636,000,000.00 MJ and the biogas generated from the anaerobic digester, which amounted to 53,998.69 kg d^{-1} was used to produce electricity equivalent to 29,797,809.57 MJ yr^{-1}. The total power produced from the co-generation facility, which burned bagasse, was 8.72 MW. This translateed to 210,955,678.50 MJ yr^{-1}. The total energy equivalent produced, equivalent to 876,753,488.07 MJ yr^{-1}, wass 275.54% of what was expended, thereby contributed a net energy gain of 558,558,298.76 MJ yr^{-1}. The values corresponded to 10.61 MJ L^{-1} bioethanol (energy expenditure), and accounting the total energy produced (29.23 MJ L^{-1}), the whole production system had a positive net energy of 18.62 MJ L^{-1} bioethanol. This is in accordance with the studies of *Mekonnen et al.* (*2018*) of Brazilian sugarcane bioethanol with 17.7 MJ L^{-1}; *Pimentel and Patzek* (*2007*) who assessed sugarcane ethanol production via fermentation in US and Brazil with 15.2 MJ L^{-1}; with *Diaz de Oliveira et al.* (*2005*) with 16.1 MJ L-1; and with *Macedo et al.* (*2004*) with 21.9 MJ L^{-1} as summarized by *Luo et al.* (*2010*). All of these assessments included energy expended in the farm and factory and in all co-products as considered in this study.

Table 5. Energetics of sugarcane bioethanol production in the Philippines including plantation, plant operation, transportation and end-use.

Item	Energetics
Expenditures	MJ yr^{-1}
Plantation	152,641,509.28
Transportation (plantation to bioethanol plant)	43,860,032.42
Plant Operation	116,835,162.61
Delivery (Bioethanol plant to composting facility)	4,858,485.00
Subtotal	-318,195,189.31
Products	MJ yr^{-1}
Electricity from Bagasse	210,955,678.50
Electricity from Biogas	29,797,809.57
Bioethanol	636,000,000.00
Subtotal	876,753,488.07
Net Energy	558,558,298.76

Scenarios for different transport distances (i.e., if distance will be doubled, then the value may also be doubled) and availability of technology for biogas conversion such that the reported value may be omitted, may easily be manipulated to adjust data as necessary and recompute to assess the energetics of the system. Plantation practices, yield, bioethanol production, and bagasse utilization may be kept constant as the data used are typical in the Philippine setting (**Table 5**).

Energetic Payback Time

The energetic payback time was computed to evaluate the time it would take to compensate the pre-operational energetic expenses. Dividing the total energetic expenses during the preoperational period (467,901,597.45 MJ) by the net energy gain (558,558,298.76 MJ), the expenses were projected to be compensated in 0.84 year (of the 280 d yr^{-1} operation, equivalent to 0.64 of the 365 days). This is equivalent to about 7.71 months or 231.34 operating days.

Water Inventory

The water inventory in the construction was calculated from the embedded water of the materials (**Table 6**).

The total water inventory in the construction level amounted to 952.64 ML, consisted of the footing (56%), the structure (25%), the equipment (19%), and the piping (1%).

Table 6. Water inventory in the construction of the designed 30-MLPY sugarcane bioethanol facility in the Philippines.

Structure	Material, Mg					Water volume, ML	Percentage
	Galvanized Sheet	Steel	Concrete	Stainless Steel	Gravel		
Structural	187.09	5,419.27	5,050.85	146.90	-	240.23	25
Equipment	-	4,412.63	-	-	-	176.51	19
Footing	-	5,727.00	100,530.78	223.46	45572.49	530.22	56
Piping	-	141.98	-	-	-	5.68	1
Total	187.09	15,700.89	105,581.63	370.35	45572.49	952.64	100

Table 7. Water consumed in the production of sugarcane bioethanol from the plantation and facility in the Philippines.

Source	Volume of Water Required (L)	Volume of Water per Volume of Ethanol ($L\ L^{-1}$)	Volume of Water per Energy Content of Ethanol ($L\ MJ^{-1}$)	Volume of Water per ton Cane Processed ($L\ Mg^{-1}$)
Plantation	82,478,360,993.82	2,749.28	129.68	192,032.52
Imbibition	535,727.12	0.02	0.00	1.25
Liming	2,233,410.70	0.07	0.00	5.20
Dilution	236,489,339.19	7.88	0.37	550.61
Co-generation facility	41,046,132.04	1.37	0.06	95.57
Condensing water	2,127,055,729.91	70.90	3.34	4,952.38
Washings	80,991,816.52	2.70	0.13	188.57
Total	84,966,713,149.31	2,832.22	133.60	197,826.09

*Note: plantation water requirement = (sugarcane water requirement at 36,000 $m^3\ ha^{-1}$ minus water available after wastewater treatment and precipitation in the Philippines); washings = (mill house waste + filter cloth washings + boiler house & floor washings, done every week)

On the one hand, the water inventory in the production or the total amount of water required to produce bioethanol from sugarcane was accounted from the field and the factory operations (**Table 7**).

According to *Reddy and Reddy* (*2003*), sugarcane needs 36 MLwater per hectare. Using the total area, the whole plantation needs 237,878.06 ML yr-1. However, the plantation can take up water from rainfall and use the treated wastewater from the factory. The data from the *World Bank Group* (*2015*) shows that an estimated average of 2,348 mm precipitation is experienced in the Philippines, (which amounts to 155,149.36 ML yr^{-1}), and the amount of wastewater that could be used for fertigation is 250.34 ML yr^{-1}, hence, additional plantation water requirement accounts only to 82,478.36 ML yr^{-1}.

The processes in the factory also need water supply, recorded as follows, in L yr^{-1}: 535,727.12 as imbibition water; 2,233,410.70 for liming; 236,489,339.19 as dilution water; 41,046,132.04 for the co-generation facility; 2,127,055,729.91 as cooling water; and 80,991,816.52 for washings. The figures considered recycling of water with 20% make-up water to account the losses. Plant operating records usually have 5-20% blowdown rate in their boilers (*Suez Water Technologies and Solutions 2020*).

The water requirement bioethanol production is equivalent to 2,832.22 L L^{-1} of ethanol produced or 133.60 L MJ^{-1} or 197,826.09 L Mg^{-1} sugarcane processed.

CONCLUSIONS AND RECOMMENDATIONS

Energy-wise, the production of bioethanol from sugarcane is very efficient since it generates 275.54% of the total energy expended during feedstock and final product manufacture. This is in accordance with the US and Brazil bioethanol production from sugarcane with energy recovered on energy invested (ERoEI) ratio of 1.48 and 2.29, respectively (*Pimentel and Patzek 2007*). These results were further improved and reassessed by *Ramírez Triana* (*2011*) and computed the ERoEI equal to 2.63. Additionally, the energy expended in putting up the bioethanol plant can be easily recovered within just about eight months of operation.

A definite quantification of the total water consumed for the given system was established at 2,832.22 L L^{-1} ethanol produced. This figure includes all water consumed from plantation to factory that has a co-generation facility. On the water consumption of bioethanol production from sugarcane in Nigeria, 62,300 L L^{-1} ethanol is consumed (*Nasidi et al. 2010*); 790 – 11,030.4 L L^{-1} in Thailand (*Chiu et al. 2016*); and 1,115 L L^{-1} in Brazil (*Mekonnen et al. 2018*). While gasoline only consumes about 2.8-6.6 (v/v) water (*Wu and Chiu 2011*), the water requirement of the crop only proves that using biomass for fuel production has a huge downside, which should be greatly taken into consideration now that the world is facing water scarcity.

The Philippines, even being an archipelago, is not excluded in facing water scarcity in the agricultural sector (*Inocencio et al. 2018*). To put the biofuel water consumption into perspective, lowland rice in the Philippines requires 1,432 L of water per kg of rice produced (*International Rice Research Institute, nd*). This means that the production of one liter of ethanol from sugarcane is going to compete for the production of 2 kg of rice. Hence, unless we develop ways to use recycled water to avoid competition with food for irrigation water, massive promotion of sugarcane-based fuel should be greatly planned.

The output of this study could serve as a basis for computation for the local inventory of bioethanol plants. The calculation methodology presented herein can be easily followed by the entities wishing to conduct their own energy and water balance. This should allow venture capitalists to estimate profitability in producing bioethanol from sugarcane. Furthermore, it could give an idea to the distilleries on areas where water may be conserved and reused, which may help the whole industry become sustainable.

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