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Is Raw Sugar Produced from Sugarcane (*Saccharum officinarum* L.) Carbon Positive or Negative ?

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Abstract Carbon footprint calculations for raw sugar manufacture was conducted with the aim of determining if the industry is carbon neutral or net contributory to carbon emission. A detailed procedure for the production of raw sugar from sugarcane was designed to account all the sources of carbon emission. The factory design was based on a capacity of 4000 tons per day, operating for 270 days per year, 24 hours per day. The total carbon footprint accounted all the emissions and savings from plantation, factory operations, and products end-use. A total of 53,099.59 kg CO_2 per hectare was computed or 643.63 kg CO_2 per ton cane or 6.31 kg CO_2 per kg sugar.

The embedded emissions of the materials during construction (pre-operational period) was also included, which served as the industry's "carbon debt." But this"carbon debt" was computed to be offset within 0.26 years.

With the co-generated electricity from bagasse fueling of 26.97MW and daily exported to the grid , the calculated carbon savings (compared to the Philippine electricity carbon intensity) was 2,089 tons CO_2 per ha per year. At the field level of cane production, no cane burning/trash farming practice could shift sugarcane production from carbon emitting into carbon sequestering (carbon negative). Hence, raw sugar produced from the sugarcane plant can be carbon negative rather than positive. This means that instead of contributing to the emission, the whole system fixes in more carbon dioxide.

Keywords: raw sugar, carbon footprint, carbon inventory, GHG emission, raw sugar production, factory, milling, sugarcane, farm, payback period

Introduction

Carbon footprint inventory is a useful tool for the determination of the environmental impacts of a process, a product, or a service. Since the global consciousness about the effects of the emission of greenhouse gases to the

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worsening climate condition, efforts towards climate change mitigation have intensified. As defined, carbon footprint (CF) is the total amount of carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions (e.g., CH_4, CO, N_2O) associated with a product or activity causing climate change (Wiedmann and Minx 2008; Walser *et al.* 2010). Quantification of carbon emission would estimate the subject's contribution to the condition and would allow definite action response if necessary.

In the Philippines, there is Executive Order (EO) 174 entitled, "Institutionalizing the Philippine Greenhouse Gas Inventory Management and Reporting System," which was signed by President Aquino last 24 November, 2014. Section 2 of this EO stipulates that there should be an accounting and reporting of GHG emissions from identified key source sectors in order to develop and maintain centralized, comprehensive, and integrated data on GHGs; develop a system for the archiving, reporting, monitoring, and evaluating GHG inventories in all key sectors; and facilitate continuous capacity building initiatives in the conduct of GHG inventories to ensure application of updated methodologies.

In our study, we calculated the carbon footprint of raw sugar manufacture . The sugar industry is one of the premiere industries in the Philippines. The processes involved, both in the field and the factory, in sugar production is an energy intensive-requiring system (Corpuz and Aguilar, 1992; Mendoza and Samson 2000; Mendoza *et al*. 2004). These processes emit greenhouse gases or carbon dioxide equivalent also called carbon footprint of the industry. In compliance to the aforementioned E.O.,a GHG inventory of the various stages of raw sugar manufacture is essential.

Mendoza (2014) had calculated the carbon footprint of sugarcane production at the farm level only. There was no detailed audit or inventory for the processing of sugarcane to raw sugar under Philippines condition. The sugar industry could be one of the major contributors of carbon emission from the country. While the Philippines contributes a small fraction at 0.27% of the total or Global GHG emissions (Godilano, 2009), it is still important to determine whether sugar production is carbon neutral or net contributory to carbon emission. If it is contributory, then measures to reduce them are the logical action.

This study aimed to quantify the total carbon footprint of raw sugar production from the sugarcane field to raw sugar manufacture. Calculations for the carbon emissions of the milling process started from construction of the factory to the regular operations. Also, the embedded carbon emissions of the materials used and the direct carbon emissions from the practices applied were included. The carbon footprint from the field were added to calculate the total carbon footprint and to determine whether raw sugar production is positive, neutral, or negative.

Materials and methods

Scope and boundary of calculations

In this study, the carbon footprint of raw sugar manufacture was calculated starting from factory construction, factory operation, and products end-use (Figure 1). Also included in the audit is the carbon footprint from the field (sugarcane production). The GHG emissions accumulated in the entire raw sugar manufacture were expressed in equivalent carbon dioxide (CO2-eq.). Final carbon account is expressed in terms of per ha, per ton cane, and per kg sugar.

Methods adopted in calculating the carbon emission in the mill

A detailed procedure calculating the carbon emission for the production of raw sugar was based from the factory design with capacity of 4000 tons per day, operating 270 days per year (off-milling season already reflected), and 24 hours per day.

Factory construction

Initially, material and energy balances were established. These balances determined the sizes of equipment and the plant layout. From this, an account for the construction materials was calculated. Carbon emissions were calculated using the "embedded carbon emission" or the total CO_2 released over the life cycle of a material. The sum of the materials used was derived from building the facilities and fabrication of equipment. The bill of materials for the construction of the facility includes components for the roofing system, wall and framings, flooring, beams and girders, staircases, handrailings, and bracings, while assembly of equipment in the plant includes base support, pipes and pumps.

The facilities included in the factory are: cane preparation and milling, heating and clarification, evaporation, crystallization, centrifugation, co-generation facility, wastewater treatment, and other buildings.

The emission from this phase is treated separately as this emission only happens before the operation. It was considered as "carbon debt" of the raw sugar production. It could be compensated or "paid back" if the system would be able to realize carbon savings. The savings could come from the carbon fixation capacity of the plant and from the surplus generation of

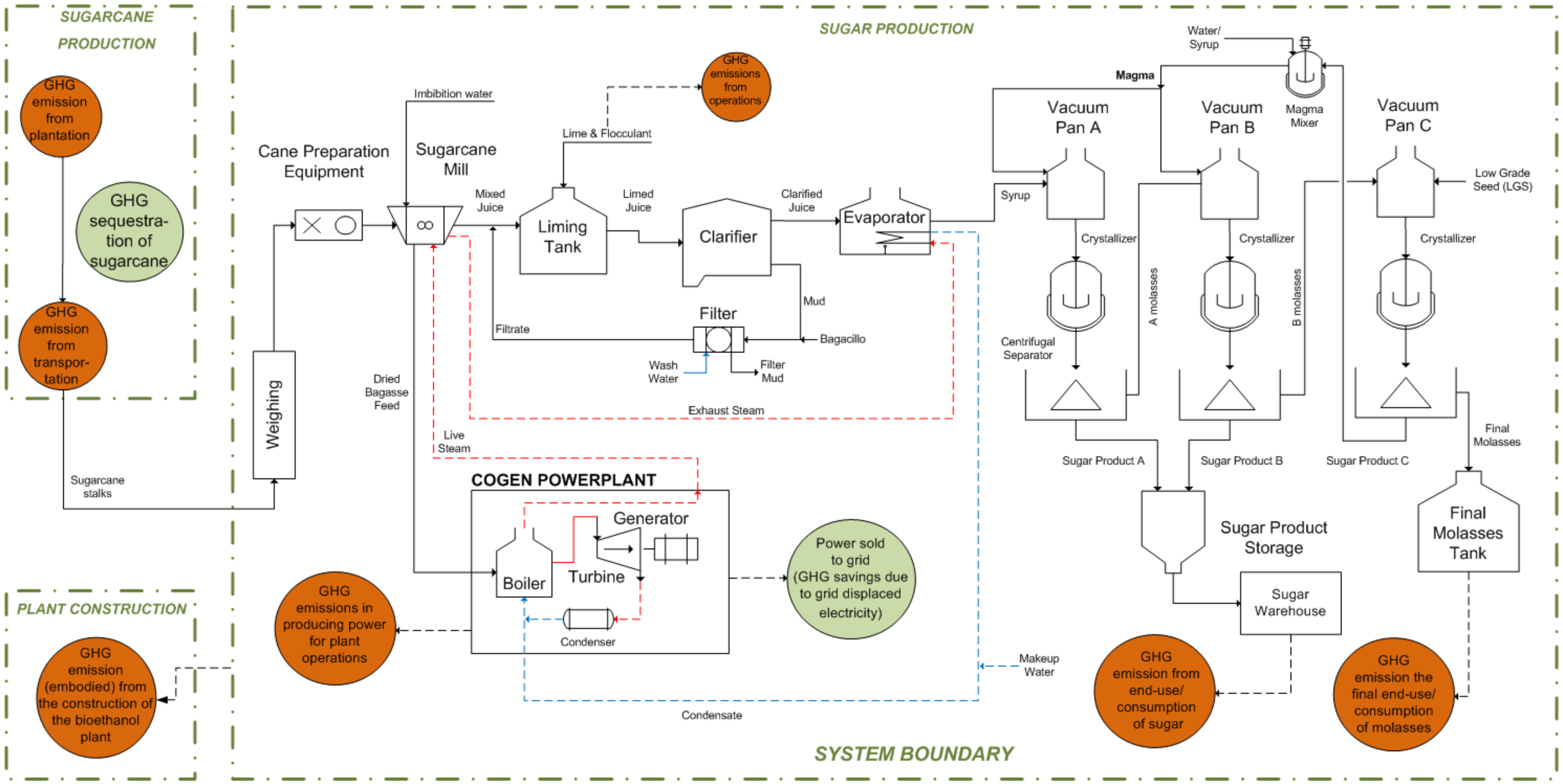

Figure 1. System boundary of the carbon footprint calculations.

electricity that could be sold to the grid. These savings were included in calculations.

The carbon emission factors for construction materials are summarized in Table 1. The data were obtained from the Inventory of Carbon and Energy (ICE) by Hammond and Jones (2011) as cited by Greenspec UK.

Table 1. Embodied carbon dioxide emission of the materials for plant construction

Material	Embodied CO_2 emission (kg-CO_2 kg-material^{-1})
Concrete	0.16
Stainless Steel	6.15
Steel	1.37
Cast iron	1.91

Hammond & Jones (2011), cited by Greenspec UK

Factory operations

The comprehensive design of the processing plant and computations of material and energy balance based on the crushing capacity of 4000 tons per day determined the requirements on input materials and the equipment sizes from which the total power consumption for the operation was estimated. The designed factory has co-generation facility that generates power from the bagasse. Additional fuel combustion from bunker oil was added to start the milling operation since bagasse was not yet available during the start up. The excess electricity generated from bagasse was sold to the grid. The carbon savings was realized from the replacement because of the lower carbon emission of bagasse fueling compared to the Philippine electricity carbon intensity **(**Table 2**).**

Table 2. GHG emission factors for the overall plant operation

Chemicals or Reagents	CO_2 emission (kg-CO_2 kg-material^{-1})
Lime (CaO)[1]	1.0302
Fuels	CO_2 emission (kg-CO_2 liter^{-1})
Diesel[2]	3.96
Gasoline[3]	2.35
Ethanol[4]	1.51
Power Generating Feedstocks	CO_2 emission (kg-CO_2 kWh^{-1})
Coal[5]	0.534
Biogas[6]	0.25
Bagasse[7]	0.522
Bunker oil[8]	0.778

1 Biograce GHG Calculation Tool Standard Values; 2 Mendoza 2014; 3 US EPA (2011) United States Environmental Protection Agency; 4 Derived value; 5 IPCC Carbon Dioxide Intensity of Electricity – Philippines; 6 Clark (2013); 7derived (US EPA, 1993); 8 BHP Billington (2011).

From the gate, a heavy-duty truck with a hauling capacity of 10 tons and fuel economy of 2.126 km per L diesel (Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET), 2013) was assumed to travel a 60-m distance to the cane unloading area. From the carriers, the stalks entered a four-mill tandem with three rollers per mill. Pol extraction efficiency was 92.5%. The extracted juice was clarified using hot liming method to produce a clarified juice with 83% apparent purity. Afterwards, the clarified juice was fed to the quadruple-effect evaporator to produce syrup with 65°Brix.

The wastewater generated from the process is treated before discharge; some are reused. Treatment was done first in an aerobic digester, then followed by a facultative lagoon. The plant generated 2,960 L of wastewater per ton cane crushed (Patwardhan 2008). Initially, the wastewater was treated in the aerobic digester for 10 days that removed 92% of COD. Until such time, it was released to the 30-acre facultative lagoon with COD and BOD loading of 234 and 117 kg ha^{-1} day^{-1}, respectively (0.5 COD/BOD). At 5 days detention time, a 95% BOD conversion was attained and produced a final BOD output of 6 mg/L, qualifying for a Class C water quality (Philippine standard) (DENR 2008) or that which can be used for irrigation. The conversion produced an equivalent amount of 400 L methane per kg COD removed (92% efficiency).

The factory yields 2.05 L-kg raw sugar per ton cane (1 L-kg = 50 kg).

Products end-use

The consumption of the products, raw sugar and molasses, was also accounted in the inventory. The carbon emission was assumed from the carbon content of the products. It was assumed that sucrose content of raw sugar is 97.5%, which translates to a carbon fraction of 0.4105 (w/w raw sugar), and sucrose % in molasses is 55% or 0.2315 carbon fraction (w/w molasses). This carbon content was translated to $CO_{2\text{-eq}}$. From the material balance, it was computed that the amount of raw sugar produced per amount of cane is 10.25% while 3.3% becomes molasses.

Emissions from the production of sugarcane

To get the total carbon emission for raw sugar production, emissions from the production of sugarcane were included. The field survey data obtained by Mendoza *et al*. (2007) cited in Mendoza (2014), were used. Sugarcane production included two crop types: plant and ratoon crop. The associated operations for each crop type were outlined as follows:

A. Plant crop: (1) land preparation– plowing, harrowing, furrowing; (2) planting–cane point preparation, hauling, distribution, planting; (3) cultivation–ridge busting, off-barring, hilling-up; (4) application of fertilizer and other chemicals; (5) harvesting and hauling of canes to the factory gate;

B. For ratoon crop: since ratoon crop starts with what is left in the field after the harvest of a plant crop, only the data in numbers 3, 4, and 5 were considered.

Cane trash burning was also considered in the inventory. It involves direct CO_2 emission and the estimates of equivalent carbon dioxide emission of the other gases (CH_4, CO, N_2O) during burning.

Assessment of raw sugar production (Carbon emitting or net CO_2 fixing?)

While the whole system emits carbon dioxide, there are also parts where there are carbon savings. Sugarcane fixes carbon dioxide in the biomass. The total carbon dioxide (CO_2) fixed was estimated from the carbon content of the whole crop: the stalk – bagasse, raw sugar, molasses; and the biomass left in the field – trash, roots, stumps. Included in the calculations was the *"opportunity savings"* generated in the electricity from bagasse that could be sold to the grid because of its lower carbon emission compared to the Philippine electricity carbon intensity.

Results and Discussion

The sugar industry was claimed to be an energy-intensive process (Corpuz and Aguilar, 1992; Mendoza and Samson 2000; Mendoza *et al.* 2004), which would typically translate to an intensive carbon footprint. As delineated earlier, four main areas were considered in the carbon emission inventory: factory construction, factory operations, and products end-use, and from the sugarcane production.

Factory Construction

Table 3 presents the carbon debt incurred in the pre-operational period (Year 0). It is shown that the total carbon dioxide equivalent from the embedded carbon of the construction materials amounted to 32,164.88 tons CO_2e. This means that even before operation, the system already has an accompanying carbon dioxide emission.

Table 3. Carbon emission breakdown in the construction of the sugar factory.

Over-all Potential CO2 Emission Distribution						
Plant Division	**Structural**		**Major Equipment,Base Support, Pipes and Pumps**		**Combined (Over-all)**	
	CO_2 Emissions (tons)	*% CO_2 Distribution*	*CO_2 Emissions (tons)*	*% CO_2 Distribution*	*CO_2 Emissions (tons)*	*% CO_2 Distribution*
Cane Supply and Transport Area 1	166.12	1%	300.29	7%	466.41	1%
Cane Supply and Transport Area 2	399.45	1%	0.00	0%	399.45	1%
Mills A1	429.73	2%	141.84	3%	571.57	2%
Mills A2	730.44	3%	0.00	0%	730.44	2%
Power Plant	6520.48	24%	2017.65	45%	8538.13	27%
Clarification	1233.41	4%	1033.94	23%	2267.34	7%
Evaporation	521.10	2%	357.27	8%	878.37	3%
Pan House	601.90	2%	625.28	14%	1227.18	4%
Tank Farm	1485.63	5%	46.06	1%	1531.69	5%
Warehouse/Workshop Area	203.02	1%	0.00	0%	203.02	1%
Fire Station Area	54.28	0%	0.00	0%	54.28	0%
Clinic	34.72	0%	0.00	0%	34.72	0%
Laboratory	32.14	0%	0.00	0%	32.14	0%
Bagasse Storage	277.56	1%	0.00	0%	277.56	1%
Sugar Storage and Bagging	188.47	1%	0.00	0%	188.47	1%
Canteen	102.55	0%	0.00	0%	102.55	0%
Administration Building	278.41	1%	0.00	0%	278.41	1%
Wastewater Treatment Facility	2.50	0%	7.85	0%	10.35	0%
Unloading Area A1	429.08	2%	0.00	0%	429.08	1%
Unloading Area A2	516.70	2%	0.00	0%	516.70	2%
Switchyard	2.50	0%	0.00	0%	2.50	0%
Mud Bin	155.46	1%	0.00	0%	155.46	0%
Parking Area	2.50	0%	0.00	0%	2.50	0%
Miscellaneous Area	13266.56	48%	0.00	0%	13266.56	41%
Total	**27,654.69**	**100%**	**4,530.17**	**100%**	**32,164.88**	**100%**

Factory Operations

From the gate, emission from the transport of canes to the unloading area emits carbon dioxide. Also, all the input materials have embedded carbon emission. The total carbon emission in factory operations was estimated from hauling, material inputs, electricity generation, and wastewater treatment facility. From the balances and equipment sizing, it was computed that the factory consumes 5.294 MW (Table 4). It is mainly contributed by the consumption in cane supply and transport with 70.41%, followed by the operation of the mills, 16.91%; boiling house, 10.10%, co-generation facility, 1.67%; miscellaneous devices and lighting, 0.50%; and the wastewater treatment facility, 0.42%.

Table 4. Summary of the total power requirement of the factory.

Plant Division	Power Rating, kW	% Contribution
Cane supply and transport	3,727.38	70.41
Mills	894.98	16.91
Boiling house	534.51	10.10
Wastewater treatment facility	22.07	0.42
Co-generation facility	88.41	1.67
Miscellaneous buildings	26.61	0.50
TOTAL:	5,293.96	100%

With the available bagasse amounting to 1,200 tons per day, the co-generation facility could generate a total of 32.26 MW power everyday. During start-up, bunker oil was used to supply the 5.294 MW requirement of the plant, with CO_2 equivalent emission of 98,849.57 kg CO_2 per year. Through the rest of the 269 days of operation, all the bagasse is burned to supply the electricity demand of the plant and sell the excess to the grid. This translates to a carbon dioxide emission of 258,949,402.71 kg CO_2 per year, constituting the 98.13% of the total emission in the factory .The rest is divided with hauling, material input, and wastewater treatment (Table 5).

Table 5. Total annual carbon inventory of the raw sugar factory.

Component	Carbon Inventory ($kgCO_2$ $year^{-1}$)	% Contribution
Hauling	24,139.98	0.01
Material Input	556,308.00	0.21
Electricity Generation	258,949,402.71	98.13
Wastewater Treatment	4,358,634.55	1.65
TOTAL	263,888,485.44	100

The total carbon emission during factory operations is 263,888,485.44 $kgCO_2$ per year or 20,158.15 $kgCO_2$ per hectare or 244.34 $kgCO_2$ per ton cane or 2.38 $kgCO_2$ per kg sugar.

Products End-use (Raw sugar & Molasses)

The total carbon dioxide equivalent emission from the consumption of the products – raw sugar and molasses, was estimated from the total carbon content. The production of raw sugar was 10.25% of the weight of the cane while 3.3% becomes molasses. The consumption of all the raw sugar emits 168,139,636.4 $kgCO_2$ while 30,501,818.18 kg is emitted by the molasses. Summing up, the total emission of the products is 198,641,454.58 $kgCO_2$ or 15,174 $kgCO_2$ per hectare or 183.93 $kgCO_2$ per ton cane or 1.79 $kgCO_2$ per kg sugar.

Sugarcane Production

The carbon footprint in sugarcane production by stages of production and in cane burning (Table 6) showed that in plant crop, 6,415.45 kg CO_2 was emitted per hectare and in ratoon crop, 5,279.44 kg/ha CO_2. The CO_2 emission was estimated from a production cycle of 1 plant crop and 3 ratoons giving an average emission of 5,563.44 kg/ha CO_2. Cane trash burning, at 12,204 kg/ha CO_2 emission constitutes 68.69% of the total emission in the farm. These values translate to 215.36 kg CO_2 per ton cane or 2.13 kg CO_2 per kg sugar.

Table 6. Carbon footprint in the field level production of sugarcane.

Stage		Emission, $kgCO_2$ ha^{-1}	% Emission
A.	**Cane production (Average of 1 plant cane + 3 ratoons)**	5,563.44	31.31
	Plant crop	6,415.45	
	Ratoon cane	5,279.44	
B.	**Sugarcane crop residue burning**	12,204.00	68.69
	Direct CO_2 emission (biotic CO_2)	10,410	
	CO_2e of CH_4	470	
	CO_2e of CO	1,240	
	CO_2e of N_2O	83	
C.	**Total CO_2 emission (kg) per ha (A+B)**	17,767.44	100
	Total CO_2 emission per (kg) ton cane	215.36	

Total CO_2 emission (kg) per kg sugar	2.13

Total Carbon Emission (Plantation, Factory Operations, and Products End-use)

Combing all the sources of CO_2 emission, the total carbon dioxide emitted through the whole process is summarized in Table 7. The plantation contributed 17,767.44 kgCO_2 per ha which is 33.46% of the total carbon emission of 53,099.59 kgCO_2 per ha; factory operations at 20,158.15 kgCO_2 per ha (37.96%); and products end-use contributed 15,174.00 kgCO_2 per ha (28.58%).

Table 7. Total carbon emission of raw sugar production in the Philippines.

Unit	kg CO_2e	% Emission Contribution
A. Sugarcane plantation:	**17,767**	33.46
Cane Production		10.48
Per ha	5,563.44	
Per ton cane	67.44	
Per kg raw sugar	0.67	
Cane Burning		22.98
Per ha	12,204.00	
Per ton cane	147.92	
Per kg raw sugar	1.46	
B. Factory operations:		37.96
Per ha	20,158.15	
Per ton cane	244.34	
Per kg raw sugar	2.38	
C. Products End-use:		28.58
Per ha	15,174.00	
Per ton cane	183.93	
Per kg raw sugar	1.79	
TOTAL		**100**
Per ha	53,099.59	
Per ton cane	643.63	
Per kg raw sugar	6.31	

Is raw sugar production net CO_2 emitting or sequestering

The sugar manufacturing systems at various stages emit CO_2 in the atmosphere. But sugarcane, a C4 crop species, (CO_2-fixation via the C4 pathway), is fixing lots of CO_2 in its various parts. The equivalent carbon dioxide fixed was estimated from the carbon content of the whole crop (Table 8). The crop is able to fix 60.111 tons CO_2 equivalent per hectare from the stalk milled in the factory and the biomass left in the field (trash, roots, and stumps).

Table 8. Indicative carbon fixed in the various parts of sugarcane crop.

	CO_2e, ton/ha
1. By the stalk:	
Bagasse	19.615
Raw-sugar	12.844
Molasses	2.330
2. By the biomass left in the field:	
Trash	17.801
Roots	1.880
Stumps	5.641
TOTAL (1+2)	**60.111**

This amount fixed makes the total system appeared as carbon sink initially. As summarized in Table 9, the net carbon footprint of raw sugar is the difference between the carbon dioxide fixed at 60.111 ton/ha CO_2e *less* emission in cane production and processing at 53.099 ton/ha CO2e = 7.011 ton/ha CO_2e. This implies that the system sequestered back 7,011.41 kgCO_2 per hectare (84.99 kgCO_2 per ton cane or 0.83 kgCO_2 per kg raw sugar).

Table 9. Total carbon footprint of raw sugar production.

Unit	**kg CO_2e**
A. Sugarcane plantation:	
Cane Production	
Per ha	5,563.44
Per ton cane	67.44
Per kg raw sugar	0.67
Cane Burning	
Per ha	12,204.00
Per ton cane	147.92
Per kg raw sugar	1.46
B. Factory operations:	
Per ha	20,158.15
Per ton cane	244.34
Per kg raw sugar	2.38
C. Products End-use:	
Per ha	15,174.00
Per ton cane	183.93
Per kg raw sugar	1.79
D. Sequestration:	
Per ha	(60,111.00)
Per ton cane	(728.62)
Per kg raw sugar	(7.11)
NET TOTAL: D-(A+B+C)	
Per ha	(7,011.41)
Per ton cane	(84.99)
Per kg raw sugar	(0.83)

But the trash burned in the field that liberated 10.41 t CO_2e/ha are used back for photosynthesis in the next crop being biotic CO_2 (oxidation of plant biomass is called biotic CO_2e as opposed to fossil fuel oil burned which is called fossil CO_2e). Same is true for bagasse that was burned for fuel and raw sugar and molasses (Table 8) that are used elsewhere and they are considered consumed (oxidized). The CO_2e fixed in the trash, stumps and roots would decompose over time joining the biotic CO_2e cycle. However, 15% of these biomass form humus–C (Batjes 1999), a stable carbon fraction that forms part of the soil organic matter (SOM) upon decomposition. From the base data used in this paper (Table 8), about 0.557tC per ha or 2.06 t CO_2e equivalent per ha is sequestered in the soil. Following the delineation of CO_2e into biotic and fossil CO_2, the fossil CO_2e emission was accounted and the result is shown in Table 10. The total fossil CO_2e emission of raw sugar production is 5,942.13kg CO_2e per ha or 72.03 kg CO_2e per ton cane or 0.43 kg CO_2e per kg sugar.

Table 10. Fossil CO_2 emission of raw sugar production.

Unit	kg CO2e	% Emission
A.Cane Production	**5,563.44**	93.63
Cane Burning		0.00
B. Factory operations*	**378.69**	6.37
Products End-use:		0.00
TOTAL--per ha	**5,942.13**	100.00
Per ton cane	72.03	
Per kg raw sugar	0.43	

**** the emission included only the bunker fuel to start the mill***

The small amount of emission in the factory operations is due to bagasse used for fuelling and bunker fuel was only used to start the mill supplying only 3.1% of the total electricity consumption.

Of the total power co- generated at 32.26 MW, only 5.294 MW is utilized in the raw sugar processing. This means that 26.97 MW is available for selling to the grid. This gives the whole system boundary carbon savings amounting to the difference in emission of the Philippine electricity and the electricity from bagasse fueling. Every day, the system saves 7,766.21 kg CO_2 (computed from the difference in carbon emission, 0.534-0.522, multiplied by 26.97 MW x 1000 x 24 hours). The total annual carbon emission *'opportunity savings'* calculated from co-generated electricity (269 days) is 2,089.11 tCO_2 per year. This translates to 160.17Kg CO_2e per ha.This slightly reduced the fossil CO_2e emission from 72.03 kg to 70.08 kg CO_2e e per ton cane and from 0.71 kg to 0.69 kg CO_2e per kg sugar.

Factory construction has *embedded mission* called carbon debt at 32,164,880 kgCO_{2e} by the total carbon savings (93,864,915.59 kgCO_{2e} per year, computed by adding the net total carbon footprint and the savings .The co-generated electricity considered sold to the grid has CO_2e emission savings of about 91,789,200 kg CO_2e (84.99 kgCO_2 per ton cane * 4000 * 270 days) . The payback period was estimated at 0.35 of the 270 days or 91.61 days of operation (or 0.26 year).

Although small, *raw sugar production is Carbon emitting at 0.69 kg* CO_2e *per kg sugar. The carbon debt is easily paid back (0.26 year) if the excess co-generated electricity could be sold to the grid.*

This being the case, this should not the drive the industry players into complacency as there are “hotspots” in raw sugar production. The identification of these hotspots could direct responses for greener practices and they could easily make raw sugar production carbon dioxide emission negative. In the field level, cane residue burning accounts for 68.69% of the emission. Aside from GHG emissions, the practice imposes a more serious effect on the soil because it impoverished the soil by depriving it from the much needed soil organic matter (SOM). SOM had decreased by almost 50% in Philippine sugarcane soils (Rosario *et al.*, 1992) because of cane burning. Low SOM leads to low fertilizer use efficiency on top of the burned nitrogen (95%, phosphorus at 20% and potassium at 70 %. This means more fertilizer should be applied to obtain the same yield, which increases the fossil CO_2 emission as fertilizer manufacture uses fossil fuel energy (oil and natural gas),thus , increasing the carbon inventory of the system.However , Mendoza (2017) reported that no cane burning/trash farming practice could shift sugarcane production from carbon emitting into carbon sequestering (carbon negative) due to the following: 1) direct C-sequestration from humus-C incorporated in the soil at 6.0 t CO_2e/ha ; 2) avoidance of emission of CH_4, CO, N_2O during cane burning at 1.794 t CO_2e /ha ; 3) Increased the ratoon cycles from the usual one to two ratoons to 4 up to 6 ratoons leads to avoided carbon dioxide emission at 0.257 t CO_2e /ha/ratoon ; 4) the conserved three macronutrients (N, P, K) at 0.814. t CO2e/ha ; 5)the avoided emission due to N-fixation in the decomposing trash that reduces the nitrogen fertilizer input to be applied to grow sugarcane at 3.09 t CO_2e /ha; or a total of 11.955 t CO_2e /ha . The calculated carbon emission in the usual sugarcane production practice centered on burning canes was 7.591 t CO_2e /ha .The ex –ante carbon balance of no burning /trash farming is 4.364 t CO_2e /ha . The challenge is how to STOP burning of canes before and after harvest by the planters in the different sugarcane producing areas

Back to the mill operations, it was observed that electricity generation was the major contributor of the emission at the factory level. Burning bagasse to power the mill generates carbon savings. Maintenance or improvement of the generation process could lessen emissions. The use of high-pressure, more efficient boilers would cut the emissions. High-pressure boilers will require smaller equipment size than their low-pressure counterpart. Also, more power will be generated per ton of bagasse by using high-pressure boilers, which will translate to more opportunity carbon savings.

Breaking down the contributors to the total electricity consumption, it was found out that 70.41% of the total power requirement was required by cane preparation and transport. The carbon emission from this area could be handled through proper maintenance of equipment. The consumption of electricity is greatly affected by the motion of the objects, which in this case could be hindered by friction (if parts are not properly greased). Friction affects the ease of the rolling equipment to rotate around its shaft. Less-resisted motion requires less power; thus, regular lubrication of the equipment would help reduce the power consumption.

Conclusion

The carbon inventory of a raw sugar processing plant showed that the whole system's carbon savings equivalent to 91,789,200 kg CO_2e year^{-1} could accumulated if the excess electricity could all be sold to the grid. Due to these savings, the system is able to offset the total carbon debt accumulated from the pre-operational period (plant construction).At the field level of cane production, no cane burning/trash farming practice could shift sugarcane production from carbon emitting into carbon sequestering (carbon negative). Hence , raw sugar production from the sugarcane plant can be carbon negative rather than positive.

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