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Reducing the Carbon Footprint of Sugar Production in the Philippines

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Abstract This study involved estimating the carbon foot print (CF) of sugar production in Eastern Batangas, Philippines whose aims were to identify the "hot spots" of sugar production, to suggest practical options to "cool" these identified hot spots, and to recommend policy options to address the social cost of carbon (SCC). The sources of CF included the detailed operations involved in sugarcane production (plant cane and ratoon) up to milling to produce raw sugar , and the associated CF in cane burning (expressed in CO_2 equivalence). The carbon foot print (CF) of sugarcane production (farm level) was estimated at 5.56 CO_2 t/ha, 16% of total (or 0.067 tCO_2/ton cane) while processing the canes in the mill contributed 47% (16.5 $tCO_{2,}$ (200 tCO_2/ ton cane, 1.98 kg CO_2/kg sugar). The conventional practice of burning canes contributed 37% greenhouse gases at 12.9 tCO_2/ha which led to a considerable increase in CF from 22.03 tCO_2/ha to 34.9 tCO_2/ha or 2.64 to 4.2 kg CO_2/kg sugar. Deducting the equivalent CO_2 sequestered in the soil due to the unburned trash, roots, and stumps retained in the soil as humus – C (at 2.06 t CO_2/ha) decreased the carbon foot print of sugar slightly from 4.2 to 3.98 kg CO_2 per kg sugar. At P13.51/t CO_2, the estimated social cost of carbon (SCC) as year 2011 was PhP 2.34/kg. The SSC of sugar is instructive to 1) the environmental cost of sugar and 2) the needed adjustments in production practices to reduce the sugar carbon foot print in order to ecologically sustain sugarcane production. There is a need to increase the soil organic matter to improve fertilizer use efficiency, soil water-holding capacity, and ultimately increase the energy efficiency of sugar production. N-fertilizer input and cane burning were the two identified major sources of GHG emission. Shifting the conventional production systems to an alternative cane production system where there would be no cane burning and only 50% N-fertilizer would be applied would lead to 40% reduction in CF, from 3.98 to 2.32 kg CO_2 per kg sugar. Accordingly, SCC would decrease from PhP2.34 to PhP 1.38 per kg sugar . Issuance of a sugar order is necessary to provide the legal basis of charging SCC to the industry key players to fund the programmatic shift of the conventional sugarcane production to an alternative systems to reduce the CF of sugar and to improve the economic viability and the long term sustainability of sugarcane production

Keywords: carbon footprint, greenhouse gas, carbon dioxide, methane , nitrous oxide, social costs of carbon, trash farming, soil organic matter, green economy

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Introduction

Sugar production (cane production in the field and cane milling in the sugar mill) is an intensive energy requiring processes (Mendoza and Samson, 2002; Mendoza *et al.*, 2004, Corpuz and Aguilar, 1992). All of the processes and inputs used directly and indirectly involved burning of fossil fuel energy. Growing and hauling canes to the mill use machines (tractors, trucks) that burn oil. The manufacture and transport of agrochemical inputs (fertilizer, herbicide) also used fossil fuel (natural gas). Certain field practices as in cane burning directly emits CO_2 and other greenhouse gases (GHG) in form of methane, carbon monoxide, nitrous oxide which have powerful global warming potential (GWP) relative to CO_2 (Weir,1998;Mendoza and Samson,2000). Collectively, when all these GHG are added together, it represents the carbon footprint (CF)* of a product like sugar. It is apparent that producing and consuming sugar (in coffee, ice cream, cakes and many other food items) is emitting CO_2 and other GHG.

These GHG causes global warming/climate change. There is now overwhelming evidence that human being activities that emit greenhouse gases causes global warming/climate change (IPCC, 2007) .Although the Philippines contribute only a small fraction (0.27%) of the Global GHG emissions, it is still important to find ways on how to reduce emissions. In sugar production, fortunately reducing emissions (or mitigating measures) is also leading to an energy efficient sugar production systems decreasing the cash costs of production (Mendoza *et al.*, 2004), contributing to the economic viability and long term ecology stability of sugarcane production (Mendoza *et al*., 2007) in the country.

Quantifying the carbon footprint of a product like sugar can be used as the basis for reducing its GHG emission (Wiedmann and Minx, 2008). The so-called "hot spots" in terms of energy consumption and the associated CO_2-emission in the production cycle can be identified. Hence, this study was conducted to quantify the greenhouse gas emission (carbon footprint) for each operations and inputs used in sugar production and express the carbon footprint per ha, per ton cane and per kg sugar. Specifically, this study aimed to (1) identify the "hot spots" of sugar production, (2) to suggest practical measures

* Carbon footprint (CF) is the total amount of carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions (e.g. methane, CO, N_2O) associated with a product (Wiedman & Mins, 2008 ,UK Carbon Trust, 2008). The causes of emissions include the agricultural processes, and all the emissions in electricity, burning of fossil fuels, transport operation and other industrial processes. CF is a subset of the data covered by a more complete life cycle assessment (LCA) an internationally standardized method (ISO14040, ISO14044) for the environmental burdens and resources consumed along the life cycle of products (EC, 2007). CF include only the emissions that have an effect on climate change.

or options to "cool" these identified hot spots and to recommend policy option to address the social cost of carbon (SCC) as result of sugar production which is consistent to the global demand of offsetting carbon emission.

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Source of Data

The primary field survey data obtained by Mendoza *et al.*; (2007) in Eatern Batangas Province, Philippines were used . The data base included the various operations at farm-level cane production as summarized in Fig.1.Two crop types were involved: plant cane and ratoon crop. The associated operations for each crop type were delineated as follows: for plant crop: 2)Land preparation - plowing, harrowing, furrowing ,2) Planting - cane paint preparation, hauling, distribution, planting ; 3) Cultivation - ridge busting, off-barring, hilling-up ; 3)Amount of fertilizer applied ; 4) Harvesting and hauling of canes . 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 obtained.

Appropriate energy values for the various field operations and inputs (fertilizer, NPK) were obtained from Pimentel (1980)), Pimentel *et al.* (1983), and Panesar and Fluck (1993) as cited by Mendoza *et al*. (2004); Mudahar and Hignett, 1985. The energy usage were converted into liter diesel oil equivalent (LDOE) as calculated by Mendoza *et al*. (2007)

Calculating the Carbon footprint of sugar production

The estimated net carbon footprint (CF) of sugar production included the following1) The carbon foot print of sugarcane production at the farm level and when the canes were milled in the factory, 2) The associated GHG-emission (expressed in CO_2 equivalence) in cane burning, 3) The net CF was estimated by deducting the carbon sequestered in the unburned trash , roots and stumps.

The carbon foot print of sugar production (farm level and when the canes were milled in the factory)

The CF of sugar production was estimated by taking the sum between the carbon footprint of sugarcane production(CF scp) and carbon footprint of sugarcane milling (CFscf) as follows :

$$CF = C_e sc + C_e scp$$

Where: CF = Carbon foot print from sugar production from sugarcane

C_e scp = Carbon dioxide emission from sugarcane production

C_e scf = Carbon dioxide emission from sugarcane milling

The carbon foot print of sugarcane production at the farm level was estimated as follows: First, the energy used in cane production (land preparation to harvesting ,including the inputs, embedded energy of machines up to transport of millable stalks to the mill were estimated and converted into common energy expression as liter diesel oil equivalent (LDOE) .The carbon foot print (CF) was computed by multiplying the LDOE/unit input or operation x 3.96 kg CO2/LDOE. The CO_2 emission from 1li diesel oil = 3.96 kg $C0_2$/li. It is the sum between the direct (3.332 kg $C0_2$/li)(IPCC: 2001) and the indirect emission (0.63 kg $C0_2$/li)(Pimentel (1980).

Nitrogen fertilizer consumed high amount of energy to manufacture. Application in the field emits CO2. A separate estimate for the CF of N was done as follows:

$$N_e\ ha^{-1} = Ne \times N_{ha}$$

Where : $N_e ha^{-1}$ = CO_2 emission for N applied per ha

N_e = CO_2 emission from per 1Kg N

N_{ha} = Nitrogen applied per ha

$$N_e = (E_N \times \frac{C_e do}{CO_2}) + N_2O_e$$

Where: N_e = CO_2 emission from per kg N

E_N = Li diesel Oil equivalent in the manufacture of N + transport to the Philippines (2.04 LDOE + 0.11 LDOE = 2.15 LDOE/kg N^{-1} ,Mendoza et al.,2007)

$C_e$do = Carbon dioxide emission from diesel oil

N_2Oe = N_2O emission from applied nitrogen where the N_2O emission from applied N = 1.5% (IPCC, 2001).

The N_2O emission was adjusted to its global warming potential (GWP-100 years) relative to carbon dioxide. The global warming potential (GWP) of N_2O = 298 (IPCC, 2007).

Then, the carbon footprint of sugarcane production(C_e scp) was estimated using the following formula :

$C_e scp = C_e ce + C_e cc + C_e i + C_e m$

Where : C_e scp = Carbon emission from sugarcane production
C_e ce = Carbon emission from crop establishment
$C_e$cc = Carbon emission from crop care to harvesting and transport of canes to the milll
C_e i = Carbon emission from inputs (i.e. fertilizer, herbicides, cane points)
C_e m =Carbon emission from the manufacture of machines (tractors & implements: hauling trucks)

The carbon footprint of sugarcane milling (C_e scm) was estimated as follows :
C_e scm = LDOE/TC x $CO_{2\ e}$ per LDOE xTC/ha
Where: C_e scf = Carbon emission from sugarcane milling
LDOE/TC=50.42 (Corpuz and Aguilar ,1992)
$CO_{2\ e}$ per LDOE = 3.96 ,

The amount of sugar produced was obtained by multiplying the tonnage (TC/ha)and the amount of sugar per ton cane (Lkg/TC). For the energy use in cane processing in the mill ,the data of Corpuz and Aguilar (1992) as cited by Mendoza and Samson (20024) were adopted. The data were obtained from 33 mills out of the 38 operating sugarcane mills in the Philippines. Milling canes up to the stage that raw sugar is produced consumed 50.42 LDOE/TC. To reconcile the data obtained in the farm with that in the mill, energy use figures were all converted into energy use per ton cane (TC) or energy use per kg-sugar where appropriate.

The associated GHG-emission (expressed in CO_2 equivalence) of cane burning

Conventional sugarcane production involved pre- and post-harvest burning of canes. Pre-harvest burning is done to facilitate cutting and loading of stalk for hauling to the sugarcane mills. Post-harvest burning is done to clean the fields and facilitate ratooning operations. Crop residue burning leads to direct and indirect CO_2 emission. The CO_2 emission from sugarcane crop residues (dried leaves+ tops) included :1)Direct CO_2 emission from residues burning , and 2) Emission from other gases (CH_4, CO,) as summarized in Fig.2.

Direct CO_2 emission from residues burning was estimated as follows:

$$CO_2 escrb = Q_{scrb} * \left[F_b \, x \, F_{10} \, x \, C\right] x \, CO_2 - C$$

Where: CO_2esrb=Direct CO_2 emission from sugarcane residue burning

Q_{srb}=quantity of sugarcane residues burned (tops & leaves)

Fb =fraction of residues burned in the field = 0.65 (Mendoza & Samson , 2000)

F_f=fraction fully oxidized = 0.90 (IPCC, 1996)

C_f=carbon fraction in residues = 0.4235 (IPCC, 2000)

3.7=CO_2 C (44/12)

Emission from other gases (CH_4, CO, .N_2O)

Methane.CO_2 – CH_4 = CH_4C x GWP CH_4 (t CO_2/ha)

Where:

CH_4=carbon dioxide equivalent from methane emission from burning of sugarcane residues

CH_4 e =methane emission from burning emissions in ton C/ha * CR

Emissions in ton C/ha = ER * Total C Released (tC/ha.yr)

ER=Emission Ratio = 0.005 (IPCC, 1996)

CR=conversion ratio = 1.33 (IPCC, 1996)

GWP CH_4(100 years) = 25 (IPCC, 2007)

Carbon monoxide.CO_2 – CO = CO_e x GWP CO (t CO_2/ha)

Where:

CO_2 – CO =carbon dioxide emission equivalent from carbon monoxide emission from burning sugarcane residues (t/ha).

CO_e=carbon monoxide emission from burning (t/ha)

=emission in t C/ha x Conversion ratio

Emission in t C /ha =ER x Total C released (tC/ha)

ER=emission ratio = 0.06 (IPCC, 1996)

CR=conversion ratio = 2.3 (IPCC, 1996)

GWP-CO=global warming potential of carbon monoxide (100 yrs) = 3.2 (IPCC, 2001).

Nitrous oxide.N_2O – CO_2 = Ec x GWP N_2O (t CO_2/ha)

Where:

Ec =Ne x CR

Ec = Emissions in t C

CR = Conversion Ratio (IPCC,1996) = 1.6

Ne = Tb xNf x ER

Ne =Emissions is N/ha

Tb = Total biomass burned (t/ha) =6.65

Nf = N fraction in biomass (Yadav,1996) = 0.004

ER= Emission Ratio (IPCC,1996) = 0.07

Carbon sequestered in the unburned trash , roots and stumps

To obtain the net carbon foot print, the equivalent CO_2 sequestered in the roots and the remaining stumps of stools were estimated. The CO_2 sequestered in the roots and stumps were estimated by calculating the stumps and the root mass formed per ha using the data of Rosario and Mendoza (1977). This involved getting the shoot root ratio (37:1) and factoring the tops (21%) and stalk (79%) and using the average tonnage of 82.5 TC/ha in the case study area.

Then, the CO_2 sequestered was calculated as follows.

$$CO_2 - seq.(r + s) = B_{r/s} * C_f * C \rightarrow H\, x\, CF$$

Where:

CO_2 seq. $(r + s)$ = CO_2 sequestered in the root or stumps

$B_{r/s}$= amount of biomass (root, stump)

C_f=carbon fraction = 0.4235 (IPCC, 2000)

CF=conversion factor of C to CO_2 = 3.7

The amount of dry biomass from the stumps was estimated based from the average quantities of stubbles left in the field after cutting at 3.6 tons/ha (Rosario and Mendoza, 1977).

Net CO_2 emissions

The net CO_2 emissions were estimated by simply subtracting the total emissions estimated in #1 and #2 to the C-sequestered in the field through the trashes, roots + stumps.

The carbon foot print data were expressed using the following units : Carbon foot print (CO_2 emission) per ha, Per ton-cane (TC), and per kg sugar.

The social costs of carbon dioxide (SCC) emission

Parry *et al.* (2007) reported the estimated toll on the 2005 social cost of carbon (SCC) at $43/tC or $12/tCO2. The annual growth rate in SCC was 2.4 percent or $13.51/tCO2 (2011) and at $1 : PhP 44, the SCC is equal to PhP 594/tCO2. Using this toll on carbon, the SCC was estimated by simply multiplying the CO_2 emission (per ha, per TC, per kg sugar) to the social costs of carbon (SCC) at PhP 574/ton CO_2.

Results and discussions

The carbon foot print of sugarcane production at the farm level and when the canes were milled in the factory

The average carbon foot print of sugarcane production (average yield of 1 plant crop and 3 ratoons = 82.51 TC/ha) was estimated at 5.563 kg ha (Table 1). Slightly higher CFP was calculated in the plant cane (6,415 kg/ha) than in the ratoon cane (5,279 kg CO_2/ha) due to the energy bill (CO_2 emissions) incurred during land preparation and planting (crop establishment).Of the various operations and inputs used in cane production, fertilizer had the highest emission at 3,927 kg CO_2/ha and 3,834 kg CO_2/ha for plant and ratoon cane respectively. On the average, the CFP of fertilizer was 77% of the cane production or 12% of the total emission. This was due to the high energy to manufacture and transport the fertilizer in the Philippines and to apply it in the field at 2.17 LDOE/ha (see CF of N fertilizer). N-fertilizer was applied at 300 kg/ha in Eastern Batangas.

Table 1. Carbon footprint (equivalent CO_2 emission) of sugarcane production Batangas (by stages of production)

	CO_2Emission
A. Plant Crop	Kg/Ha
Land Preparation	902.88
Cane points & Planting	42.69
Fertilizer (fertilizer + hauling) (2)	3927.66
Cultivation + weeding	118.80
Hauling of Canes	990.00
Agricultural Machines + implement (3)	120.78
Energy in man labor (4)	222.24
Energy in cane points	90.41
Total (Kg/ha)	6415.45
B. Ratoon Cane	
1. Fertilizing (fertilizer + hauling)	3834.04
2. Cultivation + Weeding	237.60
3. Hauling of cans to the mill	990.00
4. Agricultural machines + implement	79.20
5. Energy in man labor	138.60
Total	5279.44
Average (1 Plant cane + 3 ratoons)	5563.44
Per TC	67.44
Processing (per /Ha)	16472.21

Processing (per /TC)*	199.66
per kg sugar	1.98
(Production + Processing) per Ha	22035.66
(Production + Processing) per TC	249.63
Production+ Processing---Per Kg sugar	2.64
Average yield (TC/Ha)	82.50
Average Lkg/TC	2.02
Average Sugar yield (Lkg /Ha)	166.65
Average Sugar yield (Kg /Ha)	8332.50

*milling consumed 2.97 LDOE/TC (Corpuz and Aguilar (1992) as cited by Mendoza and Samson, 2002)

Processing sugar in the mill is energy intensive at 50.42 LODE/TC (Corpuz and Aguilar, 1992) as cited by Mendoza and Samson (2004). At 82.5 TC average per ha, the equivalent CF was 16,472.21 kg CO_2 (Table 2) or 50% of the total. To grow canes and haul it to the mill emitted only 67.44 kg CO_2 per TC but to process same tonnage to raw sugar emitted 199.7 kg CO_2. The total CF (growing and processing) was estimated at 22,035 kg CO_2/ha or 249.63 kg CO_2/TC. This translated to 2.64 kg CO_2/kg sugar.

The associated GHG-emission (expressed in CO_2 equivalence) in cane burning

Conventional sugarcane production entails burning of canes. Burning is being done before or after cutting and loading the cane stalks. From the point of view of the sugarcane planters and the harvesters, burning is necessary. For the harvesters, burning is essential to facilitate cutting the sugarcane stalks. Sugarcane is trashy. Removing the trashes consumed time for the cane cutters and when the yield is weed-infested, they obstruct cutting the stalks close to the ground. The sugarcane planters burn the trashes (dried leaves of tops) to facilitate farm operations. Hauling them in one corner in the field or mulching them in between the cane rows is difficult and too risky. The trash might be accidentally burned during the height of summer months. This would burn also the growing ratoon canes. But burning canes liberates considerable amount of CO_2 and other GHGs .The estimated direct CO_2 emission from cane burning was 10,410 kg/ha (Table 2). An additional 1,791 kg CO_2/ha was estimated from the other gases (CH_4 = 467 kg CO_2, CO = 1,241 kg CO_2, and N_2O=830 kg CO_2). This summed up to 12,204 kg CO_2/ha which translate to about 37% the total greenhouse gas emission.

Table 2. The carbon footprint (CO_2emission equivalent) from burning canes at harvest time

1. Direct CO_2emission from burning canes at harvest time	
Amount of dry residue (tops & leaves) t ha^{-1}	11.36
Fraction burned in the field	0.65
Fraction fully oxidized (1PCC, 1996) = 0.90	0.9
Total biomass burned t ha^{-1}	6.65
Carbon fraction in the biomass (1PCC, 2000)	0.42
Total C released	2.81
CO_2 eq. t CO_2ha^{-1}	10.41
2. Emission from other GHG (CH4 , CO,N2O) due to burning SC residues	
2.1. CH4	
Emission Ratio (IPCC,1996)	0.005
Total C realeased (t C ha^{-1})	2.81
Conversion Ratio (IPCC,1996)	1.33
Emission in ton C	0.0187
GWP-CH4(100YR),IPCC,2001	25.00
CH4 - CO_2 Emission in t ha^{-1}	0.467
2.2. CO	
Emission Ratio (IPCC,1996)	0.06
Total C released (t C ha^{-1})	2.81
Conversion Ratio (IPCC,1996)	2.3
Emission in ton C	0.3878
GWP- CO(100YR),IPCC,2001	3.2
CO Emission in ton CO_{2e}	1.241
2.3. N_2O	
Emission Ratio (IPCC,1996)	0.007
Total biomass burned	6.65
N fraction in biomass (Yadav,1996)	0.004
Emissions in N/ha	0.0001862
Conversion Ratio (IPCC,1996)	1.6
Emission in ton C	0.0003
GWP-CH4(100YR),IPCC,2001	278
N_2O Emission in ton CO_{2e}	0.083
Total CO_2 Emission eq. (N_2O,CH4 , CO) (Kg/ha)	1,791
TOTAL GHG Emission from cane residues burning (Kg/ha)	12,204
Per TC (in Kg)	147.930
Per Lkg (in Kg)	73.233
Kg CO_2e / Kg sugar	1.465
Average yield (TC/Ha)	82.5
Average Lkg/TC	2.02
Average Sugar yield (Lkg /Ha)	166.65
Average Sugar yield (Kg /Ha)	8332.5

Carbon sequestered in the unburned trash , roots and stumps

While sugar production emits tremendous amount of CO_2-GHG, it also sequesters C due to the unburnt trashes, roots, and stumps of stools. These remained in the field and ultimately discomposed and form Humus- C (Yadav,1996 ; Wood,1991).As shown in Table 3, the total biomass left after burning is 8,776 t/ha (3.476 tC/ha for unburned trash, 3.6 tons/ha stumps of stools, and 1.2 t/ha root biomass). The C-fraction of sugarcane biomass is 0.4235 (IPCC, 2008) and only 0.15 of the C-fraction is converted to humus-C (Batjes, 1999). C-sequestered was 0.557 t/ha or about 2.063 t CO_2/ha (at 3.7 kg CO_2/kg C).

Table 3. Carbon sequestered of unburnt trash, stumps of stools left after harvest and the roots biomass

	kg/ha
1. Unburnt trash * (.35 x 11.36)	3,976
2. Stumps of stools left after harvest (1)	3,600
3. Roots biomass (2)	1,200
Total	8,776
C sequesterd (1+ 2+ 3)	557
Equivalent CO_2 sequestered (1+ 2+ 3) kg/ha	2,063
Carbon fraction (1PCC, 2000)	.424
Carbon to Humus Conversion (Batjes, 1999)	.150

*11.36 ton ha-1 sugarcane residues (tops, leaves, trash)

The 3 main sources of GHG emission (cane production + processing + cane burning) summed up to 34,239 kg CO_2/ha or about 415 kg CO_2/TC. The total emission per kg sugar is estimated at 4.11kg (Table 4).

Table 4. Summary table for the Carbon footprint of sugarcane production Batangas and the equivalent social cost of carbon(SOC)

	CO_2 emission (Kg/ha)
A. Cane production	
1 Plant cane + 3 ratoons (Average per ha)	5563.44
Per TC (Production)	67.44
B. Cane Processing	
Processing (per /Ha)	16472.00
Processing (per /TC)	199.66
C. Production + Processing (per Ha)	22035.44
(Production + Processing) per TC	267.10
Per Kg sugar	2.64
D. CO_2 emission from sugarcane Crop Residue burning(per ha)	12204.00
Per Kg sugar	1.46
E. Total CO_2 emission per ha (C + D)	34239.44
CO_2 emission/TC	415.02
CO_2 emission /kg sugar	4.11
F. Equivalent CO_2 sequestered in the unburnt trash, roots and stumps of stools (Table 3)	2063.00
Net CO_2 emission per ha	32176.44
G. CO_2 emission /kg sugar	3.86
	2.29
F. Social cost of carbon (SCC),peso /Kg sugar*	

* Parry et al. (2007)reported that the estimated Toll on the 2005 social cost of carbon (SCC) was $43/tC or $12/t CO_2. The annual growth rate in SCC was 2.4 percent or $13.51/t CO_2. (2011) at $1: PhP 44 = PhP 594/t CO_2.

The calculated net carbon foot print after deducting the humus-C sequestered in the soil is 32,868 kg $0CO_2$/ha .This slightly reduced the CO_2 emission per kg sugar from 4.11 kg to 3.86 Kg CO/kg sugar.

Parry *et al.* (2007) reported the estimated toll on the social cost of carbon (SCC) at $43/tC or $12/t CO_2. But the SCC had 2.4% annual growth rate. By 2011, the SCC increased to $13.54/t CO_2 or PhP 594/t CO_2 ($1 = PhP 44). At 3.86 kg CO_2/kg sugar, the social cost of carbon in sugar is P2.29/kg (P3.86 x P0.594/kg).

General Discussions and Implications of the estimated carbon foot print of sugar production

The ideal or stable 350 ppm CO_2 level in the atmosphere had been exceeded (http://www.350.org/en/about/science). At present, it is greater than 388 ppm and it is increasing by 2ppm/year (Hansen *et al.,* 2010).Sugar production from sugarcane is contributing large amount of GHG causing global warming/climate change. In the field level of producing cane at Eastern Batangas, two practices (N- Fertilizer application and cane residue burning) accounted for 50 % of the total. The other 50 % is in processing canes in the factory to manufacture raw or brown sugar. Cane burning, though it facilitates harvesting and other farm operations significantly contribute to $CO_{2\text{-GHG}}$ emissions .This century old practice of burning the trash , the rationale has been discussed earlier, could no longer find merit at this point as summarized in Fig.2 (Mendoza *et al*., 2003). The GHG contribution to the total CF (Table 2) was estimated at 37%. It will soon increase. The explanation is simple. Trash-burning deprives the soil from the much needed soil organic matter (SOM) . At least 15 % of organic C in the trash is converted into Humus-C (Batjes, 1999) . SOM had decreased by almost 50% in Philippine sugarcane soils (Rosario *et al.,* 1992). Low SOM leads to low fertilizer use efficiency. This means more fertilizer should be applied to obtain the same or to prevent yield decline. In Eastern Batangas, since their soils are high in P and K, only N-fertilizer is added but in huge amount already (@ 300 kg/ha). Should trash burning, the conventional practice in the past century, be sustained, then, SOM will decrease further. This will happen at a time when oil price increase (Schlesinger ,.2010 ; Smith, 2010) , consequently, the price of N-fertilizer will follow (Rodolfo,2008 ; Pfeiffer , 2003) . Should N-fertilizer increase further instead of decreasing, it will increase the CO_2-GHG loading in the atmosphere. This excludes the other negative effects of SOM-induced decline due to trash burning (Fig. 2).

On top of this, trash burning is hazardous to human health for the farm workers and the residents in the immediate vicinity. Trash farming is not conducive to human health as synthesized by Mendoza *et al.*, (2003). Sugarcane workers have been observed to have significantly high rates of mortality due to illnesses originating from agricultural operations. A case-control study in the US suggests that people engaged in sugarcane farm-related occupations have significantly higher rates of lung cancer (Mulvey & Rothschild 1983 as cited Mendoza *et al*. (2003). According to the US Occupational Health Department (1999) sugarcane workers have an increased risk of lung cancer and this may be related to the practice of burning foliage at the time of cane cutting. The burning of the sugar fields releases fly soot to the atmosphere which contains polycyclic aromatic hydrocarbons that have mutagenic and carcinogenic properties (Zamperlini *et al*., 1997) and in India , it was also found out that an increased risk of lung cancer for workers employed in a sugarcane farm (Amre *et al.,* 1999) Work involving burning after harvesting and exposure to fibers of biogenic amorphous silica may increase the risks of lung cancer and possibly mesothelioma among sugarcane farmers (Poolchund 1991).Eliminating the field burning of residues, trash farming reduces the health hazards associated with exposure to airborne particulate matter (fly soot and biogenic amorphous silica).

Application of N-fertilizer is the single input emitting tremendous amount of GHG(13 % of total). No trash burning means the trashes left in the field shall be decomposed when the rains come. It is true that it is risky leaving the field with thick trashes . Accidental or intentional fire may happen and it will damage the growing canes. Will it be costlier to manage the unburned trash ?Let us first find out the fertilizing value of sugarcane trash. In Brazil, about 54 kg N/ha/yr gain was reported for unburned cane (Boddey *et al.,* 1995). Nitrogen fixation levels of 50-200 kg N/ha occur in trash-farmed sugarcane fields, with the higher range associated with higher trash levels. A mean value of 125 kg N/ha was recorded when trash farming was established as a practice (Patriquin, 2001). Burned cane fields lose an average of 44 kg N/ha/yr and some of the P and K are also lost through burning . In trash farming, P uptake appears more efficient as the mulch protects the soil from desiccation and permits root proliferation in the soil surface where P levels are high. Mulching permits a greater recycling of P from residues than burning and that P fertilization rates is lower where burning is stopped (Ball-Coellno *et al.,* 1993). Trash farming helps increase organic matter in the soil since 15 % of the C in the trash is converted into humus – C (Batjes,1999).

Trash burning is quik and easy but soil empoverishihg and heavy GHG emitting. Due to oil price increase, N is now PhP 57.7/kg (Urea = PhP 1,300/50kg-bag). At 125 kg N, the gain in N fixation alone is worth PhP 7212/ha/year. How much it cost to manage the trash with out burning ?Trash farming involves detrashing 2 x PhP 1500/ha = PhP 3,000, trash shredding @PhP 2,000/ha , roving guard @ PhP 1800 at 1 roving guard / 5 ha; a total of PhP 6800/ha(1USdollar= PhP43.)The monetary cost of managing the trash is more than compensated by the N-gain alone(excluding P & K-fertilizer).

Burning bagasse to power the mill is practical because it is a by-product and it saves the mill from huge amount of bunker oil to run the mill. But there are still possible options as in 1) increasing the boilers efficiency to reduce the amount of bagasse to be burned in order to crystallize the sugar crystals in the juice (Doon and Thompson, 1998). This will free the excess bagasse for other uses (i.e. particle board manufacture etc.) (ESMAP, 1993; EDUFI ,1994) ; (2) further efficient use of the heat generated in the boiler in generating electricity which can be sold in the grid. This offset the grid sourced electricity, in turn, reducing the electricity generated from burning fossil oil reducing the CO_2-GHG loading (Brown, 2008) .

It is important to address the carbon footprint in sugar production. This explains why GHG emission was given monetary value expressed as social cost of carbon (SCC) or the aggregate damaging effects of the Carbon emission. Parry *et al.* (2007) estimated toll on the social cost of carbon (SCC) was $43/tC or $12/t CO_2. But the SCC had 2.4% annual growth rate. By 2011, the SCC increased to $13.54/t CO_2 or PhP 594/t CO_2 ($1 = PhP 44). At 3.86 kg CO_2/kg sugar, the social cost of carbon in sugar is P2.29/kg (P3.86 x P0.594/kg). The SCC of raw sugar at P2.29/kg.

What shall we do with this negative effects of producing and ultimately consuming sugar ? The sugar industry is the premiere industry in the country. It must lead in re-greening and in pursuing green labor (stop burning canes) in the industry. The SCC of sugar can be used as a reference point for the amount that can be charged to the sugarcane planters and the millers (at 65:35 ratio corresponding to planter miller share) to fund the needed R/D, infrastructure, equipment and extension program to assist the farmers and millers in shifting to the alternative system of sugar production that reduce N-fertilizer use , no burning sugarcane fields (for the planters) , using efficient boilers and more recycling of heat for power co-generation(for the millers). This is consistent to the re-greening the industry and in pursuing green labor .

In Eastern Batangas, the total sugar yield in the 2 districts is about 182 million kg sugar. At SSC toll fee of P2.29/kg, the amount that could be collected will be P417 million pesos . If the estimates will be extended to the whole sugar industry (@ 2.25 million metric ton sugar produced for crop year 2010-2011), then the amount is enormous (PhP 5.15 billion). With these amount if collected yearly, an industry self- financed re-greening initiatives could generate additional green labor benefiting the rural economy and it could also benefit the soil, the planters, the environment and the society at large.

An incentive scheme can be deviced. For those who will adopt the alternative system of cane production systems (50% decrease of N-fertilizer and no burning canes), the carbon foot print of sugar would be reduced from P3.86 to P2.29 . The SCC levied per kg can be reduced to P1.36 kg CO_2 per kg sugar (Table 5). This could not just be done. Anything that is not thought of could not be done. If ever, charging SCC needs an insuance of sugar order to provide the legal basis for charging it to the planters and the millers.

Table 5. Carbon footprint of sugarcane production Batangas and the equivalent social cost of carbon (SOC) at current practice and at 50% decrease in N fert. And no burning residues

	Conventional system	Alternative system	% Rdxn
	Kg CO_2	Kg CO_2	
a. Production + Processing (per Ha)	22035.00	22035.00	
(Production + Processing) per TC	79.20	79.20	
Per Kg sugar	2.64	2.64	
b. CO_2 emission from sugarcane Crop Residue burning(per ha)	12896.00		
CO_2 emission from sugarcane Crop Residue burning Per Kg sugar			
c. Total CO_2 emission per ha (C + D)	34931.00	22035.00	37
Total Kg CO_2 emission /kg sugar	4.19	2.64	37
d. Equivalent CO_2 sequestered in the unburnt trash, roots and stumps of stools	2670.00	2670.00	
e. Net CO_2 emission	32261.00	19365.00	40
f. Kg CO_2 emission /kg sugar less e	3.98	2.32	42
g. Social cost of carbon (SCC), PhP/Kg sugar	2.34	1.38	41

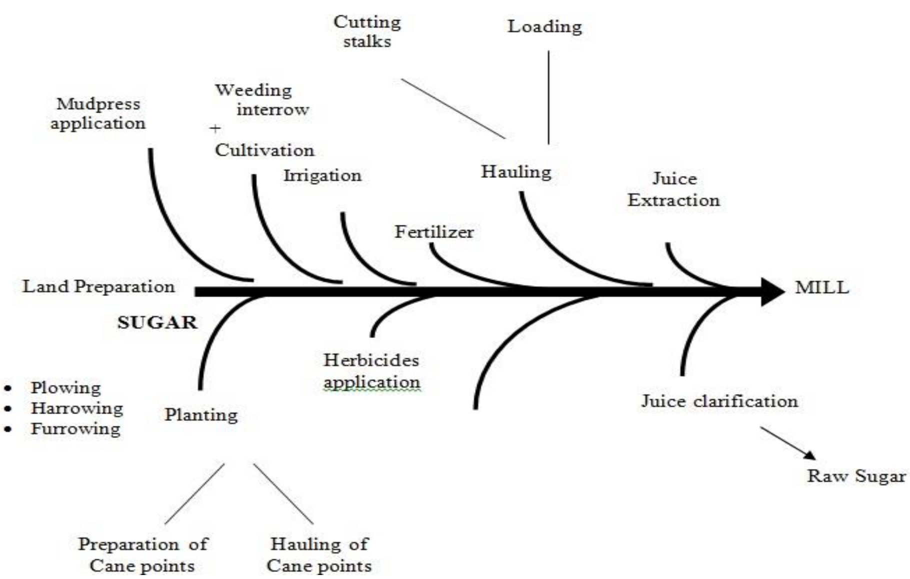

Fig. 1. Different operations involved in sugarcane production and cane milling (Mendoza &

Samson, 2004)

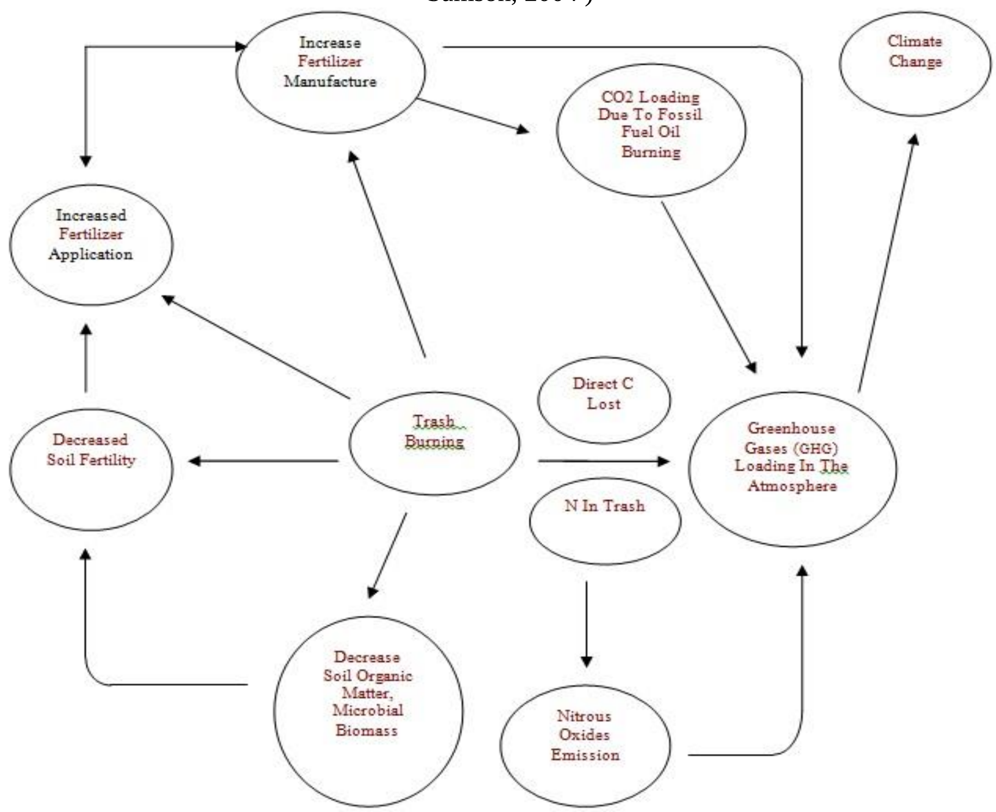

Fig. 2. Interactive (additive) effects of crop residue burning in relation to greenhouse gases loading into the atmosphere (Mendoza 2003)

Conclusion

Cane burning (37%) and heavily N-fertilizer application (13%) were the 2 aspects of sugarcane production that generated about 50% of the total carbon foot print in sugar production. The alternative system of sugarcane production (No cane burning + reduced N-fertilizer application) could reduce the carbon foot print of sugar production by 40 %

The biotic CO_2 generated by burning bagasse to generate energy in milling the canes (at 43.5% at the total CO_2-GHG in the mill) could be reduced by improving the efficiency of boilers, thus, requiring less baggasse per ton cane to process and increasing the efficiency of heat recycling to generate more electricity for the grid.

Combining the alternative system of sugarcane production (No cane burning + reduced N-fertilizer application) and improving the efficiency of boilers, and increasing heat recycling to generate more electricity for the grid;

could reduce significantly the carbon foot print of sugar . This shall reduce the social cost of carbon (SCC) of sugar production.

Charging the SCC of sugar to the planters and miller could generate sufficient funds in financing the programmatic shift of the conventional sugarcane production to an alternative system to reduce the CF of sugar and to improve the economic viability and the long term sustainability of sugarcane production. An insuance of sugar order is necessary to provide the legal basis for charging SCC to the planters and the millers.

The sugar industry, the premiere industry in the country, must lead in re-greening and in pursuing green labor in the industry consistent to the global thrusts of pursuing low carbon or green economy.

References

Ball-Coelho, B., Tiessen, H., Stewart, J. W. B., Salcedo, I. H., and Sampaio, E. V. S. B. (1993). Residue management effects on sugarcane yield and soil properties in Northeastern Brazil. Agronomy Journal 85:1004-1008.

Batjes, N. H. (1999). Management options for reducing CO2 concentrations in the atmosphere by increasing carbon sequestration in the soil. Report 410-200-031, Dutch National Research Programme on Global Air Pollution and Climate Change & Technical Paper 30, International Soil and Reference and Information.

Boddey, R. M., De Oliveira, O. C., Urquiaga, S., Reis, V. M., De Olivares, F. L., Baldani, V. L. D., and Döbereiner, J. (1995). Biological nitrogen fixation associated with sugar cane and rice: contributions and prospects for improvement. In Management of Biological Nitrogen Fixation for the Development of More Productive and Sustainable Agricultural Systems. Springer, Dordrecht. pp. 195-209.

Brown, L. R. (2008). Raising Energy Efficiency in a New Materials Economy - Part I. Retrieved from http://www.earthpolicy.org/Books/Seg/PB3ch11_ss6a.htm.

Bruce, J., Frome, M., Haites, E., Janzen, H. Lal, R. and Paustian, K. (1999). Carbon Sequestration in soils. Journal of soil and water conservation 54:382-389.

Corpuz, F. H. and Aguilar, P. S. (1992). Specific Energy Consumption of Philippine Sugar Mills. Energy Consumption of Philippine Sugar Mills. Proceedings of the Philsutech 39th Annual Convention, Bacolod City. pp. 410-421.

Doon, R. and J. Thompson. (1998). Powering the Philippine Sugar Industry into the next millennium. Proceedings of the 45th Philsutech Annual National Convention. Cebu City, Philippines, pp. 243-252

EDUFI (Energy Development and Utilization Foundation Inc) (1994). Biomass Co-generation Potential in the Philippines Sugar Milling Industry. A Joint report of EDUFI, Office of Energy Affairs, Sugar Regulatory Administration and the Philippine Sugar Milling Assoc, Inc (PSMAI), Manila, April 1994.

ESMAP. (1993). Philippines: Commercial Potential for Power Production from Agricultural Residues. Joint study of Energy Sector Management Assistance Program (ESMAP, UNDP) and the Philippines Department of Energy

Hansen, J. (2010). Target Atmospheric CO_2: Where Should Humanity Aim?. Retrieved from htpp://10.2174/1874282300802010217.

Intergovernmental Panel on Climate Change (2000). Good practice guidance and uncertainty management in national greenhouse gas inventories. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/gp/english/4_Agriculture.pdf

Intergovernmental Panel on Climate Change (2006). IPCC guidelines for national greenhouse gas inventories. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl-/index.html.

Lal, R. (1997). Residue Management, conservation tillage and soil restoration for mitigating greenhouse effect by CO2 enrichment. Soil and Tillage Research 43:81-107.

Mendoza, T. C. (2007). Energetics of Ethanol Production from Sugarcane and its Implications. Asian Life Science Journal 16:115-136

Mendoza, T. C. (2003). CO2-greenhouse gas-reducing potentials of some ecological agriculture practices in the Philippine landscape. Philippine Journal of Crop Science 26:31-44.

Mendoza, T. C. (2010). Organic Agriculture: The logical sequence to modern chemical agriculture in the Philippine Context. Annals of Tropical Research 32:112-129.

Mendoza, T. C. and R. Samson (2000). Estimates of CO_2 Production from the burning of crop residues. Environmental Science and Management 3:25-33

Mendoza, T. C. and Samson, R. (2004). Energy Costs of Sugar Production in the Philippine Context. The Phil Journal of Crop Science 27:17-26.

Mendoza, T. C. and Samson, R. (2006). Relative Bioenergy Potential of Major Agricultural Crop Residues in the Phil. The Phil Journal of Crop Science 31:11-28

Mendoza, T. C., Castillo, E. T. and Demafilis, R. (2007). The Costs of Ethanol Production from Sugarcane under Eastern Batangas Conditions. The Philippines Journal of Crop Science 32:25-48

Mendoza, T. C., Samson, R. and Elepano, A. R. (2004). Renewable biomass fuel as 'green power' alternative for sugarcane milling in the Philippines. The Phil Journal of Crop Science 27:23-39.

Mendoza, T. C., Samson, R. and Helwig, T. (2003). Evaluating the Many Benefits of Sugarcane Trash Farming Systems. The Phil Journal of Crop Science 27:43-51.

Metz, B. (Ed.). (2001). Climate change 2001: mitigation: contribution of Working Group III to the third assessment report of the Intergovernmental Panel on Climate Change (Vol. 3). Cambridge University Press.

Mudahar, M. S. and Hignett, T. P. (1985). Energy efficiency in nitrogen fertilizer production. Energy in Agriculture 4:159-77.

Parry, M. L., Canziani, J. P., Palutikof, P. J. van der Linden and Hanson, C. E. (Eds.). (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability.Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., and New York, N.Y., U.S.A. Retrieved from http://www.ipcc.ch/publications_and_data/ar4/wg2/en/spmsspm-c-15-magnitudes-of.html.

Patriquin, D. (2000). Overview of N_2 fixation in sugarcane residues: Levels and effects on decomposition. Zoology Department, Dalhousie University, Halifax, Nova Scotiat.

Pfeiffer, D. A. (2003). Eating Fossil Fuels. Available from: http://www.fromthewilderness.com/free/ww3/100303_eating_oil.html.

Pimentel, D. (1980). Handbook of energy utilization in agriculture. CRC Press, Boca Raton, Florida. 387 pp.

Pimentel, D., Berardi, G. and Fast, S. (1983). Energy efficiency of farming systems: Organic and conventional Agriculture. Agriculture, Ecosystem and Environment. 9:359-372.

Poolchund, H. N. (1991). Aspects of occupational health in the sugarcane industry. Journal of the Society of Occupational Medicine 41:133-136

Rodolfo, K. (2008). Peak Oil: The Global Crisis of Diminishing Petroleum Supply and Its Implications for the Philippines. Asian Studies Journal 41:41-101.

Rosario, E. l, Paningbatan, E. P. and Dionora, A. G. P. (1992). Study on the Causal factors of declining sugarcane quality in the La Carlota Mill DistrictProc. 39th Annual Convention PHILSUTECH Assoc. Inc. Bacolod City Phillipines. pp. 169-184.

Rosario, E. L. and Mendoza, T. C. (1977). Root and shoot growth pattern of six commercial sugarcane varieties as influenced by population density and nitrogen fertilization. The Phil Journal of Crop Science. 163 pp.

Schlesinger, J. (2010). The Peak Oil Debate Is Over. Retrieved from http://www.countercurrents.org/schlesinger011110.htm.

Smith, Clint. (2010). New Zealand Parliament Peak Oil Report: The Next Oil Shock?. Energy Bulletin. Retrieved from http://www.energybulletin.net/stories/2010-10-14/next-oil-shock.

Wackernagel, M. and W. Rees (1996). Our Ecological Footprint: Reducing Human Impact on the Earth. Gabriola Island, BC: New Society Publishers.

Weidema, B. P., Thrane, M., Christensen, P., Schmidt, J., and Løkke, S. (2008). Carbon footprint. Journal of industrial Ecology 12:3-6.

Weier, K. L. (1998). Sugarcane fields: sources or sinks for greenhouse gas emissions?. Australian Journal of Agricultural Research 49:1-10.

Wiedmann, T. and Minx, J. (2008). A Definition of 'Carbon Footprint'. Ecological Economics Research Trends. pp. 1–11.

Wood, A.W. (1991). Management of crop residues following green cane harvesting of sugar cane in north Queensland. Soil and Tillage Research 20:69-85.

Yadav, R. L. (1995). Soil organic matter and NPK status as influenced by integrated use of green manure, crop residues, cane trash and urea N in sugarcane-based crop sequences. Bioresource technology 54:93-98.

Zamperlini, G. C. M., Silva, M. R. S., and Vilegas, W. (1997). Identification of polycyclic aromatic hydrocarbons in sugar cane soot by gas chromatography-mass spectrometry. Chromatographia 46:655-663.

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