THE CARBON FOOTPRINT OF SUGAR

By

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Abstract

CLIMATE change is rapidly becoming a serious issue and one which will increasingly demand the attention of sugar producers. Estimation of the greenhouse gas emissions in the production of sugar, otherwise known as the carbon footprint, is an essential part of any sustainability study. A method of estimating net energy usage and greenhouse gas emissions has been developed, based initially on work done on biofuels. The calculation routine was developed for use in the Better Sugarcane Initiative standards, which focus on the sustainability of the sugarcane industry. This estimation procedure estimates primary energy requirements including both direct effects, mainly energy usage, and indirect effects, which include energy used in the production of fuels, fertilisers and chemicals. Allowance is also made for the inclusion of direct land use change effects. The estimation procedure allows for the production of molasses and/or ethanol, and for the export of power. Attention is given to the potential errors and problems in arriving at these estimates. The main problems are uncertainties in emissions from fertiliser use and the way in which emissions are allocated to co-products. The results show that the carbon footprint is most affected by sugarcane yield, sugar recovery, fertiliser usage, irrigation, cane burning and power export. A factory set up efficiently for maximum power generation can show a negative carbon footprint and, in this respect, maximum export of electric power can deliver a lower carbon footprint than maximum ethanol production. The calculation routine estimates the greenhouse gas emissions from field to factory gate and can be used for an existing operation or in the design of a new project to assist in making good sustainability choices.

Introduction

The issue of climate change has promoted an interest in the greenhouse gas (GHG) emissions, otherwise referred to as the carbon footprint, associated with a variety of products. The main focus has been on the production of biofuels, which has spurred the development of systems to estimate GHG emissions. Pressure is coming from the market place, through consumer expectations, and from responsible producers, to measure, control and minimise the carbon footprint of their products.

The carbon footprint of cane sugar is favourably impacted by the use of the natural fibre in sugarcane, which provides the fuel source for its production. The development of a system of calculating emissions that has wide acceptance is an important step in being able to measure and then control emissions.

It is impossible to control emissions until they are first measured. This becomes a powerful tool in the hands of producers, enabling them to assess how changes in the way they produce sugar can influence GHG emissions and one that serves as a basis for sound decision-making by business, consumers and other stakeholders.

Emissions are an important aspect of the broader subject of sustainable production. This paper focuses on the method used to estimate emissions in the production of raw sugar, and was developed as part of the sustainability standards of the Better Sugarcane Initiative.

Status of efforts to calculate carbon emissions

The major impetus for the calculation of carbon emissions has been the production of biofuels and the conditions which the EU and other importers wish to attach to imported biofuels, largely in an attempt to ensure that they are produced in a sustainable way. Sugarcane is the source of a great deal of ethanol produced, mainly in Brazil, and increasingly to a larger extent in other cane producing countries.

Thus, a number of studies have been done to estimate the net energy ratios and carbon emissions associated with bioethanol production. Different estimates of GHG emission savings relative to fossil fuels are obtained if different assumptions are made in the calculation procedure.

Wang *et al.* (2008) estimate a reduction of 78% for ethanol transported to the US from Brazil; they estimate this will increase by up to 9 percentage points if cane burning is phased out. Data produced in Brazil indicates that bioethanol produced and used in Brazil shows GHG emissions savings of 89% compared with petrol (BNDES, 2008).

The EU has compiled a Renewable Energy Directive (RED) which sets out how the emissions should be calculated for the production of a biofuel from any particular feedstock. In addition, some GHG emission saving default values, assuming no land use change, are given to be used in the absence of primary data required for its calculation.

Ethanol produced from sugarcane has the best default value of 71% emission saving relative to fossil fuels; emission savings using corn, wheat or sugar beet are significantly lower, varying between 16 and 52% depending on the feedstock and the process used.

The carbon footprint of sugar has received less attention. PAS 2050:2008 is a Publicly Available Specification, developed in the UK in conjunction with the Carbon Trust (BSI, 2008).

Recently, both British Sugar Corporation and Tate & Lyle have used this carbon footprint and labelling initiative to evaluate the carbon footprint of sugar, using a life cycle analysis approach. Renouf and Wegener (2007) have calculated the carbon footprint for raw sugar production under three different Queensland scenarios.

In the US, there has been controversy surrounding the net energy ratio and the GHG emissions for ethanol for use as automobile fuel produced from corn, relative to gasoline. The results of a number of studies have illustrated clearly how the input assumptions can radically affect the estimated quantities.

Various studies on the net energy value of ethanol from corn have been compared by Farrell and co-workers at UC Berkeley (Farrell *et al.*, 2006). Their EBAMM (ERG Biofuels Analysis Meta-Model) spreadsheets are available on the internet and are used as the basis for the computations here.

A number of other carbon calculators are available on the internet, mostly designed for the production of biofuels, which also take into account the distribution and use of the biofuels. The Renewable Fuels Agency in the UK provides an on-line calculator, as does the GREET (Greenhouse Gases, Regulated Emissions and Energy Use in Transport) model produced by the Argonne National Laboratory in the US (Wang *et al.*, 2008). This list is not exhaustive and various other calculators are available from specialist consultants.

System boundary

In conducting life cycle analyses, it is important to define the boundary of the system under investigation. The scope of the system being investigated has a substantial effect on the computations. In the case of sugarcane, the best approach considers the system to contain each individual mill and its growers as a unit, rather than a company owning and operating more than one mill. In the case of IPPs (Independent Power Producers) providing steam and power to a mill from bagasse that has been provided by the mill, the IPP should be considered together with the mill concerned. All the activities of a plant on one site should be considered, to reflect the sustainability of the total system producing food, fuel, energy and chemicals.

The system boundary includes growing and processing of sugarcane, but also includes embedded energy inputs. It starts with the manufacture of fertiliser and chemicals. Farming operations include chemicals application, irrigation, tillage and harvesting.

The cane is processed to sugar and molasses or ethanol, and may include export of electric power or bagasse. No allowance for transport of products from the factory is allowed for. The system is illustrated in Figure 1.

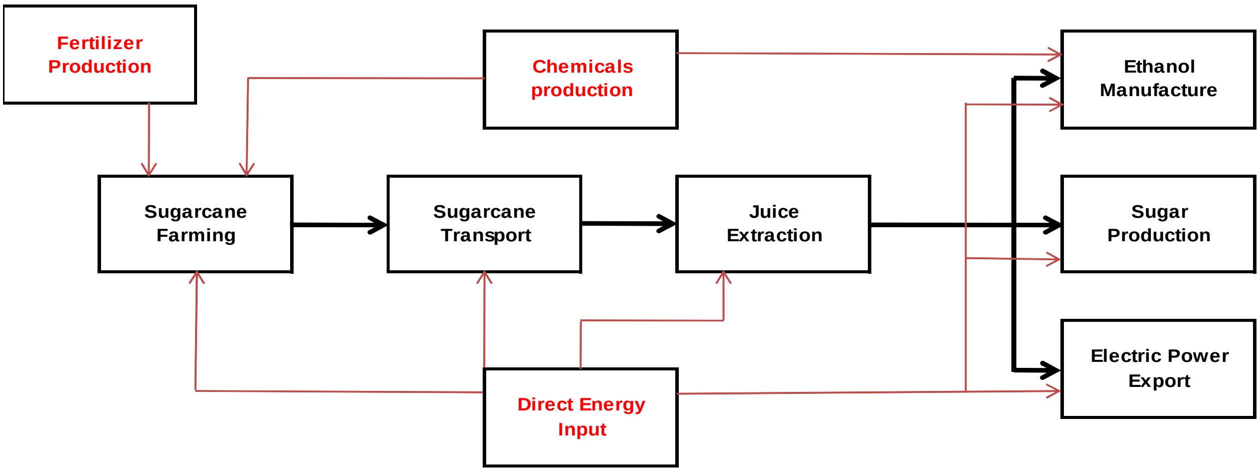

Fig. 1—System boundary assumed for GHG emissions calculation.

There are two commonly used descriptions for life cycle analyses, Business-to-Business (B2B) and Business-to-Consumer (B2C). The former accounts for the provision of inputs, including products, to a third party that is not the end user (cradle-to-gate); the latter accounts for the provision of inputs, including products, to the end user (cradle-to-grave), thus including the packaging and transport of products to the retailer/consumer, as well as the recycling and disposal of packaging waste.

This analysis represents a B2B analysis, considering the operation of a cane sugar processing facility, producing raw sugar and/or ethanol at the factory gate.

Direct and indirect effects

The energy and GHG calculations are associated with direct energy inputs and at a second level by indirect inputs.

Direct inputs are mainly fuel and power inputs, expressed in terms of the primary energy value (taking into account e.g. the efficiency of conversion of fuel to power, and the energy in producing gasoline and diesel). Indirect inputs include, in addition, the energy required for the production of chemicals, fertilisers and other materials used.

In some cases the indirect inputs also include the additional energy necessary for the manufacture and construction of farm, transport and industrial equipment and buildings. There is as yet no uniformity in different approaches.

PAS 2050 (BSI, 2008) dictates that the GHG emissions arising from the production of capital goods used in the life cycle of the product should be excluded from the assessment of the GHG emissions of the life cycle of the product. This is also the approach taken by Concawe (2007), the RTFO in the UK and the EU RED. American approaches tend to include this energy; in this analysis, it is excluded.

Land use change

It has been suggested that land use changes due to large scale sugarcane expansion could lead to significant changes in the soil carbon. This could result in additional emissions by sacrificing carbon storage and sequestration as land is diverted from its existing uses. These changes can be separated into direct and indirect components:

- *Direct* land change refers to a change from the original state of the land to use for sugarcane production. Depending on the previous use of the land in question, it is surmised that the land use change can unlock some of the carbon in the existing soil and vegetation.
- *Indirect* land use change concerns secondary effects induced by large scale expansion. This displaces existing crops, leading to expansion of crop land elsewhere, either in the same country or in other parts of the world. The effects of these changes are very difficult to estimate, and have generally been neglected in any analyses, largely because of the uncertainty in modelling the effects.

Searchinger *et al.* (2008) postulated that taking account of both direct and indirect land use change will make most biofuel ventures GHG positive, rather than reducing GHG emissions. This is based on the assumption that, as biofuel crops displace other crops, commodity prices rise and new land is put to crop cultivation in various countries, particularly Brazil, China, India and the US. Their results have been disputed by a number of people; for example, Kim *et al*. (2009) suggest that sustainable crop management practices significantly reduce the direct land use effect, while indirect land usage estimates are too uncertain to have any validity, depending substantially on what assumptions are made.

The Gallagher report prepared for the UK government released in 2008 concludes that GHG emission estimates must include the effects of indirect land use change and also avoided land use from co-products. The report recommends that biofuel production should target only idle and marginal land and make more use of wastes and residues. It also calls for sustainability standards to be extended beyond biofuels to all agricultural production.

The EU RED allows for a substantial credit of 29 g CO_2eq/MJ for a period of 10 years if severely degraded or contaminated land is used for biofuel crop purposes. Klenk and Kunz (2008) have shown that, in the case of ethanol production from sugar beet and wheat, the co-products replace other feedstuffs which would have required additional land, and so actually free up land for other crop production. In some developing nations, the land can actually be improved by diligent farming.

Because the methods and data requirements for calculating emissions from indirect land use change are not fully developed, the assessment of emissions arising from indirect land use change is not included in any current estimation procedures, but this is likely to change in the future.

In general it is accepted that direct land use change after a cut-off date must be taken into account. The PAS 2050 standard proposes a cut-off date of 1 January 1990, but the EU RED suggests 1 January 2008. In the absence of better information, the table of IPCC default land use change values for selected countries published in the PAS 2050 can be used (BSI, 2008). For perennial cropland, the default values are of the order of 15 to 25 t CO_2eq/(ha.y) for conversion of forest land and 1.5 to 7 t CO_2eq/(ha.y) for grassland. The values for forest land conversion are punitive and sufficient to derail development of new cane estates.

Handling of co-products and multiple products

A co-product is any one of two or more products, where one cannot be produced without the other being produced. An example is molasses, which is not produced unless sugar is produced at the same time. Sugar and ethanol produced in a mill would be regarded as multiple products. Waste products are defined by the IPCC as having no economic value, and will have zero allocation of energy and emissions.

Different methods of handling co-product credit have been suggested. The Concawe report (Concawe, 2007) as well as ISO 14044 lifecycle assessment standards favour the ‘substitution’ or ‘displacement’ method, which attempts to model reality by tracking the likely fate of by-products. Each co-product generates an energy and emission credit equal to the energy and emissions saved by not producing the material that the co-product is most likely to displace. Other studies have used ‘allocation’ methods whereby energy and emissions from a process are allocated to the various products according to mass or energy content or monetary value. These allocation methods are attractive because they are simpler to use, but they have little logical or physical basis, and allocation on monetary value varies by region and over time. In the event that substitution is not feasible, ISO 14044 standards recommend allocation by economic value. Although the prices may change over time, the relative market prices between joint products may be less subject to variation than absolute prices.

The displacement method has been favoured in the US in determining the credit to be applied to co-products, particularly DDGS (Farrell *et al.*, 2006; Gabroski, 2002). In the case of corn ethanol, sensitivity analysis has shown that co-product allocation has the greatest individual effect on calculations.

In the case of sugarcane processing, a factory exporting power or bagasse can apply a credit in terms of energy and emissions saved. Thus, the use of the term ‘GHG emissions’ actually refers to ‘net GHG emissions’ after applying a credit for energy exports. Wang *et al.* (2008) assume that electricity exported by the mill displaces electricity generated with natural-gas electric power plants. This is contrary to PAS 2050 which dictates displacement of energy with the country’s average generation mix.

In terms of efficiency, cogeneration is intrinsically superior to conventional power generation. Conventional technologies convert into useful power about 30% – and in extreme conditions up to 50% – of the energy in the fuel. Cogeneration systems, by directing otherwise wasted heat to meet thermal needs of the process, achieve efficiencies exploiting 85% of the fuel’s efficiency (BNDES, 2008). Potentially, using 50% of the cane tops and leaves, generating steam at 105 bar and 525°C, should enable the year-round export of 158 kWh/t cane processed. A process for gasification could increase power generation to yield above 180 kWh/t cane processed.

Where a factory produces only sugar and molasses, the allocation in proportion to market value is most easily adopted; in most cases, the allocation to molasses is less than 10% of the total and the products it displaces (e.g. animal feed components) may be difficult to identify in different countries.

In the case of a factory producing more or less equivalent quantities of sugar and ethanol, the split of energy input and GHG emissions between the two products becomes a more difficult issue. The EU RED requires that allocation should be by energy content of the products. Sugar has a calorific value of 16 500 MJ/t and ethanol 21 MJ/L; on the basis that 600 L of ethanol are produced from one tonne of sucrose, this implies an ethanol equivalent value of 16 500/600 = 27.5 MJ/L for sucrose. On this basis, 57% of the emissions should be allocated to sugar and 43% to ethanol.

In the case of an autonomous distillery, where the only product is ethanol, the problem disappears, and energy use and emissions are related to litres of ethanol produced.

Assumptions and methodologies involved

Components contributing to emissions

CO_2 from sugarcane emitted in combustion and in ethanol fermentation is considered zero CO_2 emission to the air, because this is the carbon taken in from the air during sugarcane growth. CO and VOCs emitted in combustion are assumed to be converted to CO_2 fairly rapidly, but methane and nitrous oxide (N_2O) from burning bagasse must be accounted for in GHG emissions.

CO_2 emissions arising from biogenic carbon sources are excluded from the calculation of GHG emissions from the life cycle of products, except where the CO_2 arises from direct land use change.

The greenhouse gases covered in the Kyoto protocol are CO_2, N_2O, CH_4, SF_6, methylene chloride, certain ethers, perfluorinated compounds and hydrofluorocarbons. Only the first three are relevant here. Methane and N_2O have global warming potentials 25 and 298 times that of CO_2 respectively (IPCC, 2007). The carbon equivalent value is calculated by multiplying the mass of one of these gases by its global warming potential. This is added to the CO_2 evolved and expressed as CO_2 equivalent (CO_2eq)

Methane produced in anaerobic digesters that is used as fuel in boilers is not considered to produce GHG emissions. Methane produced by anaerobic processes from wastes but not captured has to be taken into account in calculating emissions. Where methane is combusted without the generation of useful energy (i.e. flaring), no GHG emissions shall be incurred where the methane being combusted is derived from the biogenic component of the waste.

Default and secondary data

In some cases, secondary data (obtained from sources other than direct measurement) may be used to calculate emissions in preference to primary data to enable consistency and, where possible, comparability. Generally used secondary data used here are:

- Global warming potential of greenhouse gases
- Electricity emissions (in kg CO_2eq/kWh) from various energy sources
- Energy content of fertilisers per kg
- Energy use of pesticides and herbicides per kg
- Embedded energy and emissions for process chemicals
- Fuel emissions per litre
- Waste emissions per kg
- N_2O and CH_4 emissions from burning bagasse
- N_2O and CH_4 emissions from burning cane
- Direct land use change
- Agriculture emissions from soils

Default values used have been collected from a number of sources and are given in the Appendix. The EU RED suggests a more detailed treatment of default values which can give more accurate results where the particular type of nitrogenous fertiliser is specified.

Calculation method

The calculation approach adopted in this study is similar to that used in the EBAMM model, which itself is similar to the GREET model. These models have been used mainly to model the production of biofuels from corn, and they have had to be modified for sugarcane to incorporate additional issues as follows:

1. Modifications to incorporate sugar manufacture as the major activity. This includes power, fuels and lubricants.
2. Emissions due to cane burning. This is based on IPCC emission factors for burning biomass of 0.07 kg N_2O/t dry matter and 2.7 kg CH_4/t dry matter.
3. Allowance for N_2O emissions from filter cake, vinasse and cane residue left in the field. This assumes 1.225% of N in the residue is converted to N in N_2O (Macedo *et al.,* 2008).
4. Emissions of CH_4 and N_2O in burning bagasse in sugar mill boilers; values of 30 and 4 g /1000 MJ energy in bagasse respectively are used (Wang *et al.,* 2008).
5. Energy value of process chemicals.

6. A credit for molasses (where produced) based on its economic value relative to that of sugar.
7. Emissions from anaerobic treatment of effluent in the case that methane is not captured and used as a fuel. IPCC guidelines suggest 0.21 t CH_4 produced per t COD removed.
8. Allowance for any imports of molasses, bagasse and/or other biomass.

Difficulties associated with agricultural chemicals

The GHG balance is particularly uncertain because of nitrous oxide emissions. N_2O emissions can vary by more than two orders of magnitude, depending on a complex combination of soil composition, climate, crop and farming practices.

The use of nitrogen fertilisers results in GHG emissions in two stages: fertiliser manufacture (primarily CO_2 emissions from energy used) and fertiliser application (primarily N_2O emissions from nitrification and denitrification processes in the soil).

The assumption is made that 1.325% of N in nitrogen fertiliser is converted to N in N_2O through nitrification and denitrification, following the IPCC recommendations.

Various studies in Australia have focussed on GHG emissions, and how they are affected by soil type, moisture conditions and trash blanketing (Allen *et al.,* 2008; Denmead *et al.*, 2008; Denmead *et al*., 2005).

These studies estimated that N_2O emissions from Australian sugarcane soils may be higher and more variable than the emission factor of 1.325% recommended by the IPCC. Wang *et al.* (2008), however, showed that, for conditions approximating average conditions in Queensland, the emissions factor is close to the IPCC value.

Agricultural lime application results in GHG emissions from both production energy use and in-soil reactions that release CO_2. These latter emissions are poorly understood and are a source of uncertainty. The EBAMM model uses the IPCC factor of 0.44 kg CO_2eq/kg lime, which assumes that all C in lime becomes CO_2. This is the upper limit; it is possible in weakly acidic soils that limestone results in a net sink of CO_2.

Calculation results

A typical sugar mill has been modelled, based on processing 500 tonnes cane/hour and producing only sugar and molasses. The average values for the base case considered are shown in Table 1.

This assumes a conventional mill producing only sugar and molasses, processing 50% burnt cane, with some power imported for use in irrigation and some exported.

The results are summarised in Table 2. Net energy use in the agricultural operation is 206 MJ/t_C (MJ/tonne cane) and in cane transport 26 MJ/t_C. The combined number of 232 MJ/t_C is slightly higher than the comparable value calculated for Brazil centre-south conditions of 210 MJ/t_C.

The total energy usage of 278 MJ/t_C is reduced by the export of power, to give a net energy usage of 98 MJ/t_C. This is a substantial reduction, largely due to the multiplier for exported power of 2.5 to convert the exported power to its primary energy value, based on an average conversion efficiency of primary energy to power of 40%.

An average emissions factor of 150 g CO_2eq/MJ for electricity production is assumed; in practice, the value relevant to the country considered would need to be used.

The total GHG emissions are 0.43 g/g sugar, but when the credit for molasses production and power export is applied, this drops to 0.31 g CO_2eq/g sugar. In this instance, with the relative prices for sugar and molasses used, 7% of the GHG emissions are allocated to molasses. The emissions associated with molasses are < 0.1 g CO_2eq/g molasses.

A breakdown of the energy usage and GHG emissions is illustrated in Figures 2 and 3.

Table 1—Input data for base case net energy usage and GHG emissions calculations.

Cane processed	2 000 000	t cane / y
Crop yield – cane harvested	80.0	t cane / ha
Average cane age at harvest	12	months
Processing hours / y	4000	h
Sugar production / y	222 222	t sugar
Molasses % cane	3.5	t/100 t cane
Prices / t sugar	330	$
Prices / t molasses	80	$
Cane / seed cane	7.0	ha cane/ha seed
N Application rate, as elemental N	75.0	kg/ha
P_2O_5 application	75.0	kg/ha
K_2O application	75.0	kg/ha
Lime application	1000.0	kg/ha
Herbicide application rate	2.2	kg/ha
Insecticide	0.16	kg/ha
Diesel used in agriculture	100	L/ha
Electric power	90	kWh/ha
Electric power used in irrigation	450	kWh/ha
Cane Burnt	50	%
EM in cane (50 % moisture)	8	t/100 t cane
Total EM (Extraneous Matter)	140	kg DM/t_C
Average cane transport distance (1 way)	10	km
Average payload	20	t cane
Average diesel consumption	1.7	km/L
Filter cake produced	5	t/100 t cane
Factory lime usage	0.7	kg/t_C
Caustic soda used	100	g/t cane
Make-up process water	10	L/t_C
Boiler feed water chemicals used	100	g/t cane
Biocide enzymes and flocculants used	18	g/t_C
Bagasse burned	0.29	t/t_C
Bagasse LCV	7315	MJ/t
Average power exported	10	MW
Electric power imported	0.3	kWh/t_C
Factory coal consumption	1.0	kg coal/t_C

Table 2—Summary of energy and emission calculation results.

	Net energy usage (MJ)		GHG emissions (kg CO_2eq)	
	per t cane	per t sugar	per t cane	per t sugar
Total agricultural phase	206		34.3	
Transportation of cane	26		2.4	
Processing	46	417	10.8	97
Total production	278	2 505	47.5	427
Power exported	180		10.8	
Processing production net	–134		0.0	
Total production net	98	885	36.7	330
Allocation to molasses	7	199*	2.6	74*
Allocation to sugar		822		307

*per tonne molasses

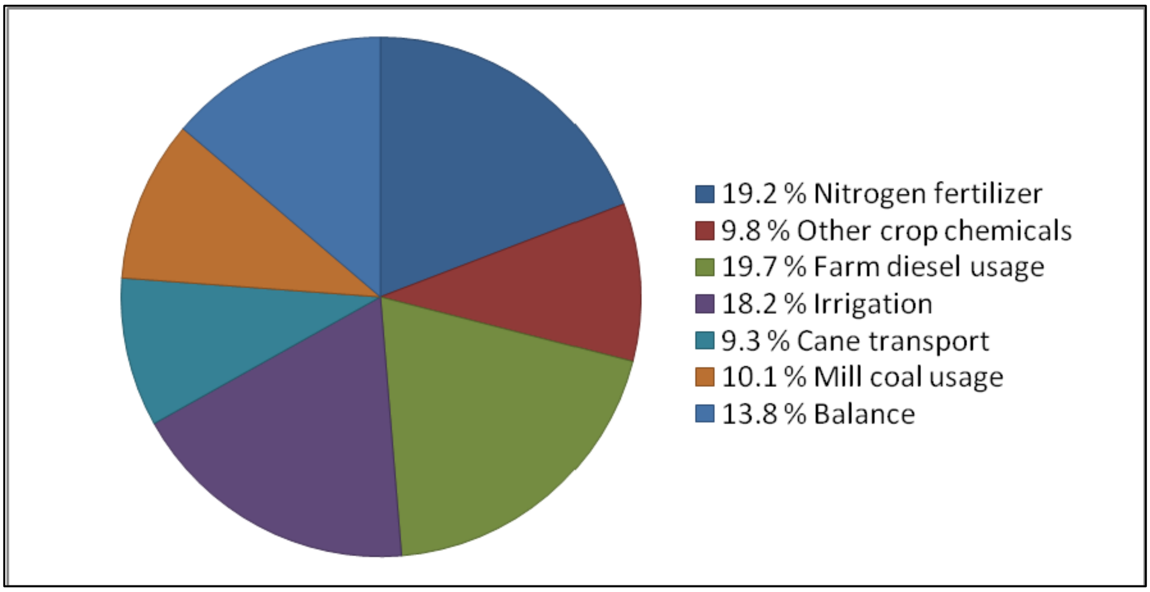

Fig. 2—Breakdown of base case calculation primary energy usage categories by %.

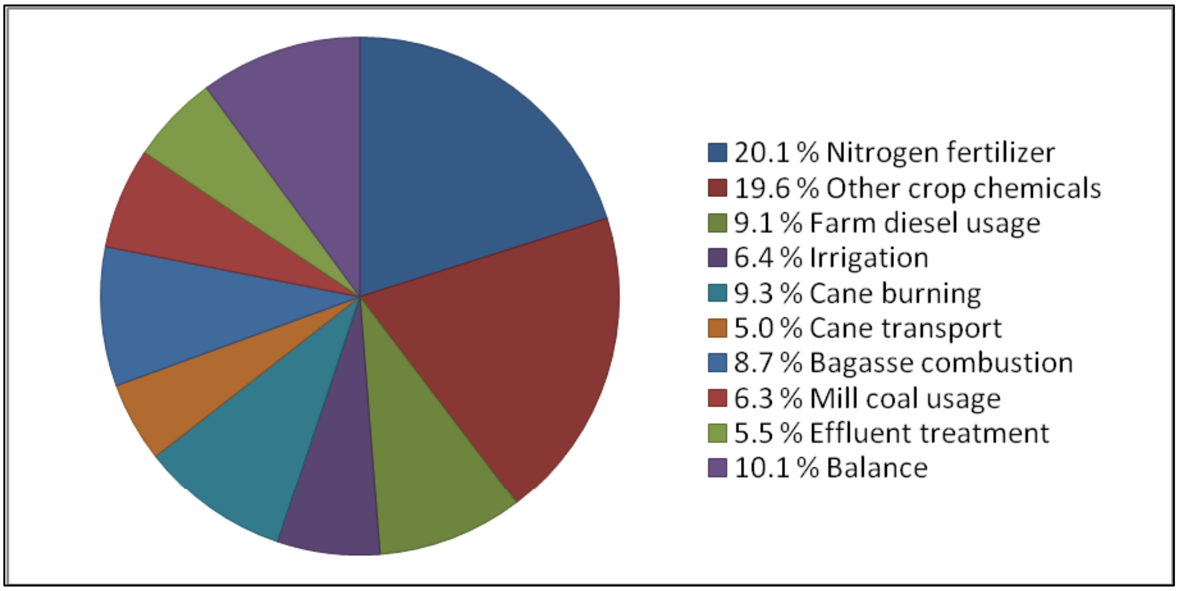

Fig. 3—Breakdown of base case calculation GHG emissions by %.

Emissions from the use of nitrogen fertilisers and lime in the fields account for almost half the emissions from the agricultural operations. The uncertainty introduced by the use of these fertilisers has a significant bearing on the reliability of the emissions estimates. Burning of cane in the fields also has a significant effect, comprising 10 to 15% of agricultural emissions when the total crop is burnt.

These values assume that all sugarcane lands were established before the cut-off date, thus excluding direct land change effects. The effect of direct land use change is very significant. If it is assumed that all cane land is established from grassland, use of the average of IPCC default values of 4 t CO_2eq/(ha.y) leads to doubling of the carbon footprint, before any credits, to 0.86 g CO_2eq/g sugar.

After credits for molasses and power, the footprint at 0.73 g CO_2eq/g sugar is more than double that of the base case. If it is forest land that is converted, the penalty in terms of GHG emissions is too large to bear.

Sensitivity to input parameters

A sensitivity analysis was carried out to show the effect of changes in the assumptions that have the greatest effect on the calculated values. This is a simplified analysis, since it assumes that changing one variable at a time does not affect any other variables. Impacts of the most important variables are shown in Table 3. It is apparent that the yield of cane per ha and the recovery of sugar in the mill (cane/sugar ratio) both have a substantial effect. The cane transport has a less significant effect on GHG emissions. The quantities of N fertiliser and lime added also have a considerable influence. The effect of emissions in the field is known to be uncertain and variable and so could be responsible for considerable uncertainty in the values obtained. The extent of cane burning is also very significant; it leads to significant amounts of CH_4 and N_2O emissions, with a high global warming potential. Cane residues left to rot in the fields lead to much lower GHG emissions.

Table 3—Effect of changes in major variables on energy usage and GHG emissions.

		Energy usage (MJ)				GHG emissions (CO_2eq)		
		Agric.	Process	Total net	Total net	Agric.	Total	Total net
		MJ/t_C	MJ/t_C	MJ/tc	MJ/t sugar	kg/t_C	g/g sugar	g/g sugar
Base case		206.1	46.4	98.4	822.4	34.3	0.43	0.31
Parameter varied from base case:								
Cane yield	50 t/ha	329.8	46.4	222.0	1857	50.9	0.58	0.45
Cane yield	120 t/ha	137.4	46.4	29.6	248	25.1	0.34	0.23
Cane/sugar	7	206.1	46.4	98.4	650	34.3	0.33	0.24
Cane/sugar	11	206.1	46.4	98.4	990	34.3	0.52	0.37
N fertiliser	30 kg/ha	173.7	46.4	66.0	552	28.6	0.38	0.26
N fertiliser	150 kg/ha	260.1	46.4	152.3	1274	43.9	0.51	0.39
Lime use	0 t/ha	196.6	46.4	88.8	742	27.3	0.36	0.25
Lime use	2 t/ha	215.7	46.4	107.9	902	41.3	0.49	0.37
Irrigation	0 kWh/ha	155.5	46.4	47.7	399	31.3	0.40	0.28
Irrigation	900 kWh/ha	256.8	46.4	149.0	1246	37.4	0.45	0.33
Cane burnt	0%	206.1	46.4	98.4	822	31.3	0.40	0.28
Cane burnt	100%	206.1	46.4	98.4	822	37.3	0.45	0.33
Power export	0 MW	206.1	46.4	278.4	2327	34.3	0.43	0.40
Power export	40 MW	206.1	46.4	–441.6	–3693	34.3	0.43	0.04
Cane transport	0.5 × base	206.1	45.7	84.8	709	34.3	0.42	0.30
Cane transport	2 × base	206.1	47.7	125.5	1049	34.3	0.45	0.33

The major influence on energy and GHG emissions is the extent of power export. The base case assumes that 10 MW is exported on average during the crushing season, representing 20 kWh/t_C in this case. Reducing this to zero increases the net GHG emissions by about one third. Conversely, if the export is increased to over 80 kWh/t_C, the GHG emissions actually become negative. This does not mean that the system is actually abstracting CO_2 from the atmosphere, but rather that the effect of power replaced gives a negative balance. A negative net energy use is also obtained.

The use of sulfitation, with a high dosage of 500 g S/t_C, has a small effect, only increasing the emissions figure by 0.02 g CO_2eq/g sugar.

If the energy embedded in capital plant and equipment is included, as some schemes propose, the overall effect is small. The net energy usage increases by about 50 kW/t_C, but the GHG emissions increase by only 0.02 g CO_2eq/g sugar.

If the blackstrap molasses produced is all converted to ethanol (18.2 ML/y), the GHG emissions are little changed. If they are allocated to sugar and ethanol according to the energy value of the products, the emissions factor for sugar reduces to 0.29 g CO_2eq/g sugar, and the emissions for ethanol are 388 g CO_2eq/L or 18.3 g CO_2eq/MJ.

If ethanol only is produced, the net energy used increases to 118 kW/t_C or 1.5 MJ/L ethanol. Carbon emissions are 488 g CO_2eq/L ethanol or 23.0 g CO_2eq/MJ. This compares with estimates for the Brazilian centre south region of 417 and 436 kg CO_2eq / m^3 of ethanol for hydrous and anhydrous ethanol respectively, or 20 g CO_2eq/MJ (Macedo *et al.*, 2008).

Results of other studies

Tate & Lyle report a figure for white cane sugar of 0.38 g CO_2eq / g sugar in a 1 kg consumer pack. Previously, they had reported a value of 0.5 g CO_2eq / g sugar, taking into account refining, packing and transport, and recycling and disposing of packaging waste (Houghton-Dodd, 2008).

The growing and milling activities are responsible for 0.19 g CO_2eq / g sugar. The figure reported by Tate & Lyle for beet sugar in the same study is almost 1 g CO_2eq / g sugar.

Renouf and Wegener (2007) report much higher values in the range of 0.5 to 0.8 g CO_2eq / g sugar. These values are inflated by higher estimates of nitrogen emissions from fertiliser, by irrigation and emissions from energy embedded in agricultural capital equipment.

Florida Crystals market ‘carbon-free’ sugar, achieved through the cogeneration and sale of electric power. Their power generation facility can produce 80 MW from 103 bar steam, using the mill bagasse as well as 900 000 tonnes of wood waste/year diverted from landfills as the fuel source.

British Sugar used the procedure of PAS 2050 to arrive at a figure of 0.6 g CO_2eq / g sugar. This is the B2B figure, as provided to the industrial user. About 60% of the emissions are due to fuel use at the factory (pers. comm. P. Watson 2009).

Use of cogeneration in the manufacture of ethanol from wheat particularly in combination with a gas-fired turbine can significantly improve energy and emission improvements relative to gasoline (Concawe, 2007). This strategy is put to good use in British Sugar’s operations.

Strategies to reduce carbon emissions

Any strategy to reduce overall energy use, minimise the use of raw materials and other inputs, and reduce waste will lead to a reduction in the carbon footprint. It seems, therefore, that a low carbon footprint will generally be a consequence of an efficient operation.

In the sugarcane industry, particular improvements can be achieved by focussing on the following, in roughly the following order of importance:

- Cogenerate and export power to the maximum extent possible
- Maximise cane yield and factory recovery
- Reduce the amount of fertiliser and chemical inputs, particularly N fertiliser
- Reduce the extent of cane burning to zero
- Reduce the quantities of any supplementary fuels purchased.
- Minimise irrigation power input.
- Reduce cane transport distances
- Recycle water to reduce water intake.

Other avenues to explore could involve the generation of biogas from wastes. Vinasse from 1 m^3 of ethanol treated anaerobically produces 115 m^3 of biogas, which in turn can generate 169 kWh of power, after deducting the power used in the process (BNDES, 2008). This can help to augment the amount of power available for export.

Conclusions

It is anticipated that, in the future, the carbon footprint associated with the production of sugar in any cane growing area of the world will have to be declared. This paper provides a way to do this, using currently accepted practices. It is an objective of the Better Sugarcane Initiative to get agreement on a standardised system of estimation both within the sugar industry and the international consumer markets.

The carbon footprint of sugar at the factory gate is expected to be about 0.3 g CO_2eq/g sugar on average. In a country where the average per capita consumption is 30 kg sugar per annum, the emissions from the consumption of sugar will be 10 kg CO_2 per capita per year. In the UK, the average individual carbon footprint is about 11 t/year – clearly sugar consumption plays a minuscule part in an individual's carbon footprint.

The carbon footprint of sugar is low by comparison with other products, particularly when full use is made of energy production in conjunction with sugar. This can be used to promote the use of sugar, particularly by comparison with other sweeteners.

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APPENDIX

DEFAULT VALUES USED

Most of the default values are obtained from the EBAMM model (Farrell *et al.,* 2006), often based on the GREET model using data from Shapouri *et al.* (2004) and Graboski (2002), or from Macedo *et al.* (2008).

Fertiliser and agricultural chemicals, in MJ/kg:

	Energy demand (MJ/kg)	Emissions factor (kg CO_2eq/kg)	Emissions on application (kg CO_2eq/kg)
Nitrogen (elemental)	56.9	4.0	6.2
Potash (K_2O)	7.0	1.6	
Phosphate (P_2O_5)	9.3	0.71	
Lime ($CaCO_3$)	0.12	0.07	0.44
Herbicide	355.6	25	
Insecticide	358	29	

Data from EBAMM

Primary energy inputs and emissions:

	Energy Demand (MJ/MJ fuel)	Total emissions (g CO_2eq/MJ)
Gasoline	1.14	85
Diesel	1.16	91
Fuel Oil	1.24	96
Natural Gas	1.12	66
Coal	1.00	107
Electricity	2.5	150*

Energy demand data from Macedo *et al.* (2008), emissions from EBAMM
*Average value; country specific values should be used.

The energy value is multiplied by the energy demand factor to give the primary energy value.

Embedded energy and emissions for process chemicals:

	Energy demand (MJ/kg)	Emissions factor (g CO_2eq/MJ)
Lime (CaO)	0.1[1]	95[1]
Biocide	3.0[2]	95[1]
Nitrogen	56.3[3]	95[1]
Caustic	75	95[1]
Sulfuric acid	2.4	95[1]
Anti-foam	10	95[1]
Miscellaneous	50	95

[1] Macedo *et al.* (2008); [2] Mortimer *et al.* (2004); [3] EBAMM

L'EMPREINTE CARBONE DU SUCRE

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MOTS-CLES: Empreinte Carbone, Énergie,
Canne à Sucre, Sucre, Éthanol.

Résumé

LE CHANGEMENT climatique est à devenir rapidement un problème grave qui exigera de plus en plus l'attention des producteurs de sucre. Estimer les émissions de gaz à effet de serre dans la production de sucre, aussi connu comme l'empreinte carbone, est une partie essentielle de toute étude de durabilité. Une méthode d'estimation de l'utilisation net d'énergie et des émissions de gaz à effet de serre a été développée, basée sur les travaux effectués sur les biocarburants. Le calcul habituel a été développé pour être utilisé dans les normes de la Meilleure Initiative de la Canne à Sucre, qui mettent l'accent sur la durabilité de l'industrie sucrière. Ce calcul estime les besoins en énergie primaire y compris les effets directs, principalement la consommation de l'énergie, et les effets indirects, qui comprennent l'énergie utilisée dans la production de combustibles, d'engrais et de produits chimiques. Il prévoit également les effets sur le changement d'utilisation des terres. La méthode d'estimation comprend la production de mélasse et/ou d'éthanol et l'exportation de l'énergie. Les erreurs potentielles et les problèmes rencontrés pour arriver à ces estimations sont pris en compte. Les principaux problèmes sont les incertitudes liées aux émissions de l'utilisation d'engrais et la façon dont les émissions sont allouées pour les coproduits. Les résultats démontrent que l'empreinte carbone est plus affectée par le rendement de canne, la récupération du sucre, l'utilisation des engrais, l'irrigation, le brûlis de la canne et l'exportation de l'énergie. Une usine efficiente, configuré pour un maximum de production d'énergie, peut montrer une empreinte carbone négative et, à cet égard, l'exportation d'énergie électrique maximale peut montrer une empreinte carbone inférieure à la production d'éthanol maximale. Le calcul habituel des émissions de gaz à effet de serre des champs à l'usine peut être utilisé pour une unité existante ou dans la conception d'un nouveau projet pour aider à faire les bons choix durables.

LA HUELLA DE CARBÓN DEL AZÚCAR

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PALABRAS CLAVE: Huella de Carbón,
Energía, Caña de Azúcar, Azúcar, Etanol.

Resumen

EL CAMBIO climático se ha convertido en un tema muy serio y requerirá cada vez más de la atención de los productores de azúcar. Estimar las emisiones de gases del efecto invernadero en la producción de azúcar, conocida también como la huella de carbono, es una parte esencial de cualquier estudio de sostenibilidad. Se ha desarrollado un método para estimar el uso neto de energía y las emisiones de gases de invernadero, basado inicialmente en trabajos anteriores realizados en bio combustibles. La rutina de cálculo fue desarrollada para ser usada en los estándares de la Iniciativa para Mejor Azúcar (Better Sugarcane Initiative, Reino Unido, en inglés) la cual se enfoca en la sostenibilidad de la industria de la caña de azúcar. Este procedimiento de cálculo estima los requerimientos de energía primarios, incluyendo tanto los efectos directos como el uso de energía y los indirectos como la energía empleada en la producción de combustibles, fertilizantes y productos químicos. También se pueden incluir los efectos de los cambios provocados por el uso directo de la tierra. Este procedimiento de cálculo también incluye la producción de melazas y/o etanol y la exportación de energía. Se ha prestado atención a los errores potenciales y a los problemas que se deriven de llegar a estos estimados. Los principales problemas son las incertidumbres de las emisiones derivadas del uso de fertilizantes y la forma en que las emisiones son adjudicadas a los co-productos. Los resultados muestran que la huella de carbón está afectada en mayor proporción por el rendimiento de azúcar, la recuperación de azúcar, el uso de fertilizantes, el riego, la quema y la exportación de energía. Una fábrica planificada para obtener máxima eficiencia en la generación de energía puede mostrar una huella de carbón negativa y a este respecto, la mayor exportación de energía puede derivar en una huella de carbón más baja que la producción de alcohol más eficiente. La rutina de cálculo estima las emisiones de gases del efecto invernadero desde el campo hasta las puertas de la fábrica y puede ser usada para una operación existente o en el diseño de un proyecto nuevo para la adecuada toma de decisiones que garanticen la sostenibilidad del mismo.