Life Cycle Inventory Data for Brazilian Sugarcane Production

IEA Bioenergy: Task 39

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Executive Summary

Life Cycle Assessment models often rely on data that is collected for specific production processes. This data can be collected for the specific process that is being assessed or it can be aggregated information portions of the lifecycle that are beyond the direct control of the party undertaking the life cycle assessment.

Secondary data is information that is usually beyond the control of the party authorizing the lifecycle assessment work. This secondary data can include the emissions from power generation, or natural gas production. In the case of biofuels it also often includes information on the production of the feedstock.

A unique opportunity arose to develop a LCI dataset for sugarcane production through the implementation of the RenovaBio program in Brazil. As part of the RenovaBio certification program, producers were required to have a third party verify the information that they used to calculate the carbon intensity of their ethanol production. The audited results were published for public comment and then at the end of the comment period the information was removed from public view.

The process ran through 2019 and 2020. In 2020 there were 67 mills that published their performance data for public comment. There were a few cases where the mills used conservative default values rather than actual values for some of their inputs so this reduced the sample size.

The data set that was developed from this public information represented 153 million tonnes of sugar cane in total, and 138 million tonnes of sugarcane that were produced using all actual values. The details of the dataset are presented in this report. The information in this report should be of value to lifecycle database and LCA model developers.

While the carbon intensity results are of interest to the public and some policy makers, it is the underlying data that is of value to other GHG modellers as each model may have slightly different system boundaries or approaches to the calculations.

The RenovaBio calculator uses the input data presented in this report and calculates the carbon intensity for the operation. The calculated emissions may be used as a check on the emissions reported in other models.

These emissions are calculated using the GWPs from the IPCC 5th Assessment report. They use the 100 year GWPs without feedback. The emissions are presented using the lower heating value of ethanol.

The emissions calculated for sugarcane production are shown in the following figure. The weighted average carbon intensity for mills that did not use default values in the calculator was 23.2 g CO_2eq/MJ. The ethanol production at the mill adds 1-2 g/MJ to the feedstock emissions in most cases. The gasoline comparator in RenovaBio is 87.2 g CO_2eq/MJ.

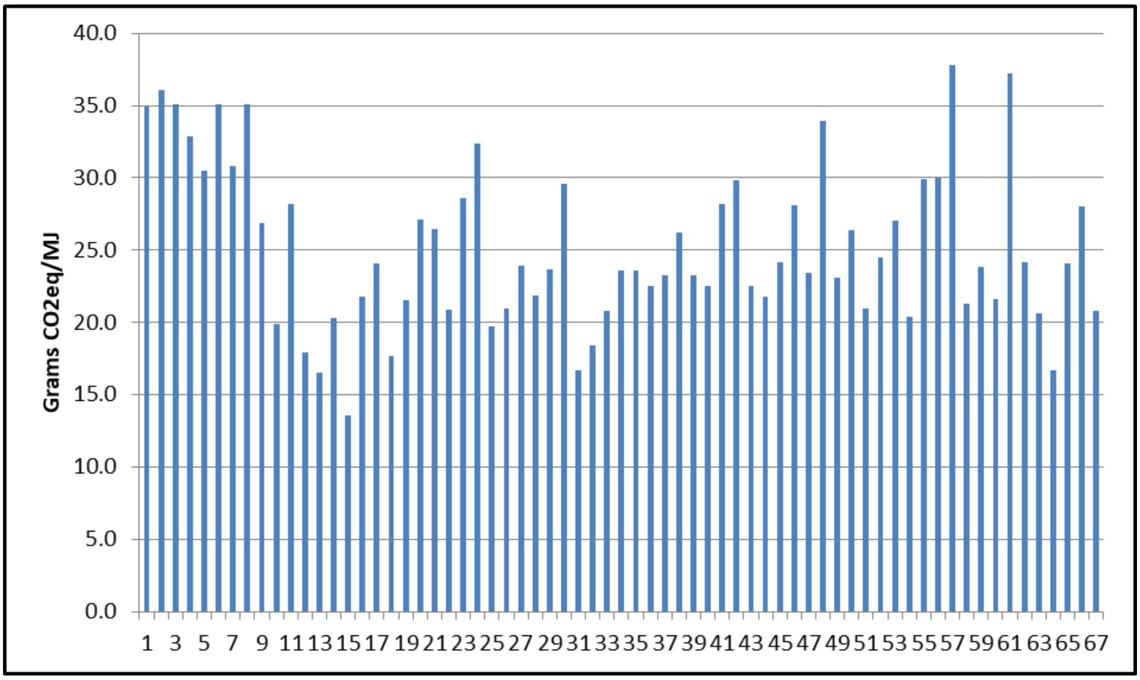

Figure 1 Sugarcane Production Emissions

It was not the goal of this work to investigate the factors that impact the CI of sugarcane ethanol but rather to develop a good dataset that would be of value to LCA modellers. However, as with many crops the quantity of nitrogen fertilizer that is applied has a large impact on the fuel carbon intensity. Other factors such as the size of the plantation and the percentage of the area that is burned before harvesting are not strongly correlated with the carbon intensity of the sugarcane produced.

ACKNOWLEDGEMENTS

Thanks to Marco Buffi of the European Joint Research Centre and Michael Wang of Argonne National Laboratory for reviewing the first draft of this report. Addressing their comments added value to the final report.

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Introduction

Life Cycle Assessment models often rely on data that is collected for specific production processes. This data can be collected for the specific process that is being assessed or it can be aggregated information portions of the lifecycle that are beyond the direct control of the party undertaking the life cycle assessment.

The ILCD Handbook notes that a wide range of potential LCI data sources exist:

- Primary data sources are the producers of goods and operators of processes and services, as well as their associations.

- Secondary data sources which either give access to primary data (possibly after re-modelling / changing the data) and to generic data are e.g. national databases, consultants, and research groups.

Secondary data is information that is usually beyond the control of the party authorizing the lifecycle assessment work. This secondary data can include the emissions from power generation, or natural gas production. In the case of biofuels it also often includes information on the production of the feedstock.

A unique opportunity arose to develop a LCI dataset for sugarcane production through the implementation of the RenovaBio program in Brazil. As part of the RenovaBio certification program, producers were required to have a third party verify the information that they used to calculate the carbon intensity of their ethanol production. The audited results were published for public comment and then at the end of the comment period the information was removed from public view.

The process ran through 2019 and 2020. In 2020 there were 67 mills that published their performance data for public comment. There were a few cases where the mills used conservative default values rather than actual values for some of their inputs so this reduced the sample size.

The data set that was developed from this public information represented 153 million tonnes of sugar cane in total, and 138 million tonnes of sugarcane that were produced using all actual values. The details of the dataset are presented in this report. The information in this report should be of value to lifecycle database and model developers.

RENOVABIO

RenovaBio is the Brazilian National Biofuels Policy, which was established with the following objectives:

- Provide an important contribution to the fulfillment of the commitments made by Brazil under the Paris Agreement;

- Promote the adequate expansion of biofuels in the energy matrix, with emphasis on the regularity of fuel supply; and

- Ensure predictability for the fuel market, inducing gains in energy efficiency and reduction of greenhouse gas emissions in the production, sale and use of biofuels.

RenovaBio established annual national decarbonization targets for the fuel sector, in order to encourage increased production and participation of biofuels in the country's transport energy matrix.

A carbon intensity calculator was developed that calculated the carbon intensity of ethanol and biodiesel production using mostly actual data from the producers.

The inputs for the calculator were made public for each producer that applied for a RenovaBio certificate. The input sheet that was used is shown in Appendix 1. The biofuel producers hired inspection firms that had been authorized by the Government to carry out the certification process. Each certificate is valid for three years and thus a new round of certification will start in 2022 and continue into 2023.

The time period that the data represents was not included in the requested information but the audit reports indicate that data was collected from a harvest year.

There was no information collected with respect to land use change over time.

While the carbon intensity results are of some interest it is the underlying data that is of value to other GHG modellers as each model may have slightly different system boundaries or approaches to the calculations.

Sugarcane Production

Sugarcanes belong to the grass family, Poaceae. It is native to the warm, temperate tropical regions of the world. Sugarcane, on average, accounts for nearly 80% of global sugar production, with sugar beet production accounting for most of the remaining sugar production. The FAO reported that sugarcane was grown in 94 countries in 2019. Production in Brazil accounted for 37% of the world's production and the top ten producing countries accounted for 85% of the world's production.

Sugarcane is a perennial grass, although the productivity declines with age. The standard practice is to replant the crop after five or six seasons.

RenovaBio Data

Actual data for all 67 operations are included for the production of sugarcane, total area involved in the production system and the area burned. The summary of the data collected is shown in Table 1.

Table 1 Sugarcane Area and Production

	Excluding plants that use default values for fertilizer use	Including plants that used default values
Total Area, ha	2,286,438	2,542,411
Total production harvested for grind, t cane	138,400,168	153,681,022
Quantity purchased by the biofuel producing unit, t cane	107,658,040	121,608,508
Burnt Area, ha	681,774	937,746
Percent burned	30%	37%
Sugarcane moisture content	52.9	53.6

Production Quantity

A total of 153 million tonnes of sugarcane were produced by the 67 mills that data was collected from. This represents 20% of the FAO reported sugarcane production in 2019.

The total sugarcane produced was reported of the 67 operators. In most cases it was equal to the sugarcane processed by the operator but there were a few cases where some of the sugarcane was sold to other operators or was purchased from other producers. The quantity of sugarcane produced by each operator varies as shown in Figure 2.

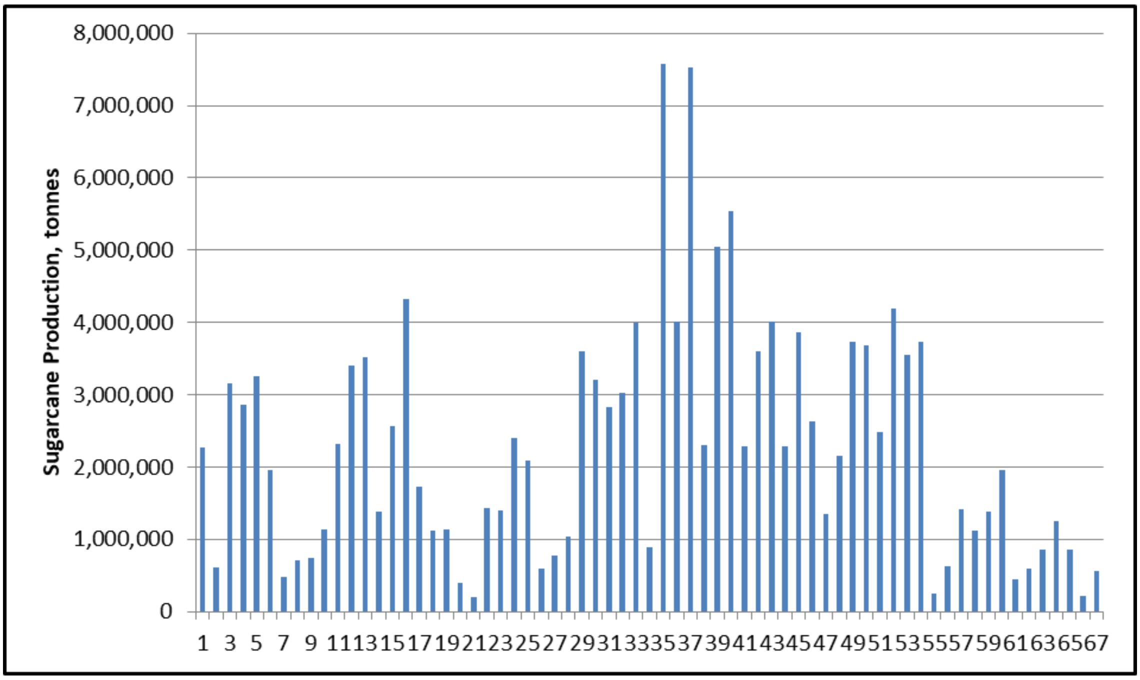

Figure 2 Distribution of sugarcane production between participants

Production Area

The production area reported in the RenovaBio data sheets included more than just the area in sugarcane production. It included the area in roads, the mill, and any area that was not in production during the year that the data was collected. The information can't be used to get the yield of sugarcane production. The distribution of the size of the operations is shown in Figure 3.

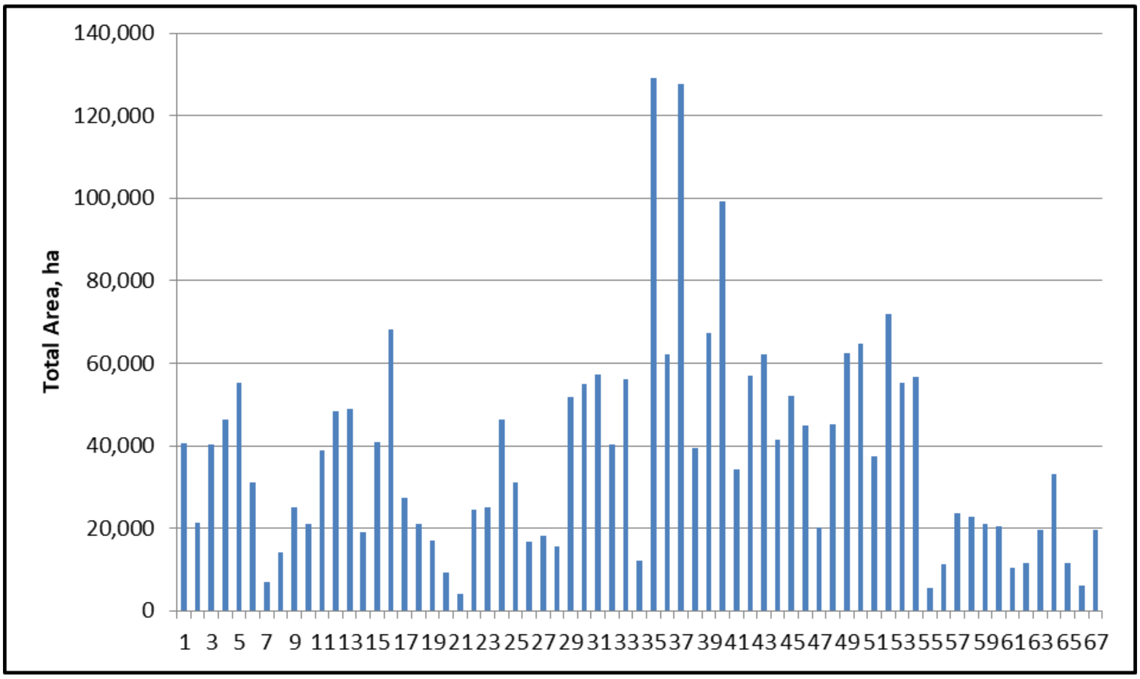

Figure 3 Distribution of the Area for each Participant

Area Burned

Burning of sugarcane fields prior to harvesting used to be the standard practice, however this is no longer allowed in some regions of Brazil. A number of producers reported some burned area. The distribution of percent of area burned is shown in Figure 4.

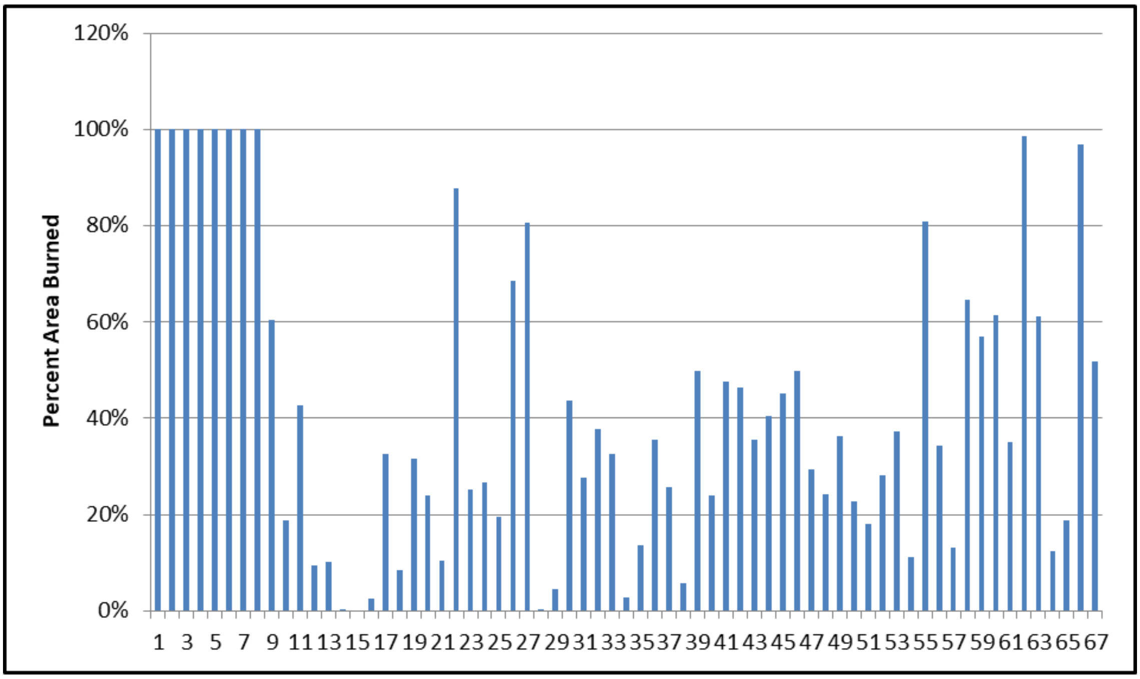

Figure 4 Percent of Area Burned

Sugarcane Moisture

The sugarcane moisture content reported by the individual mills is shown in Figure 5 Sugarcane Moisture Content

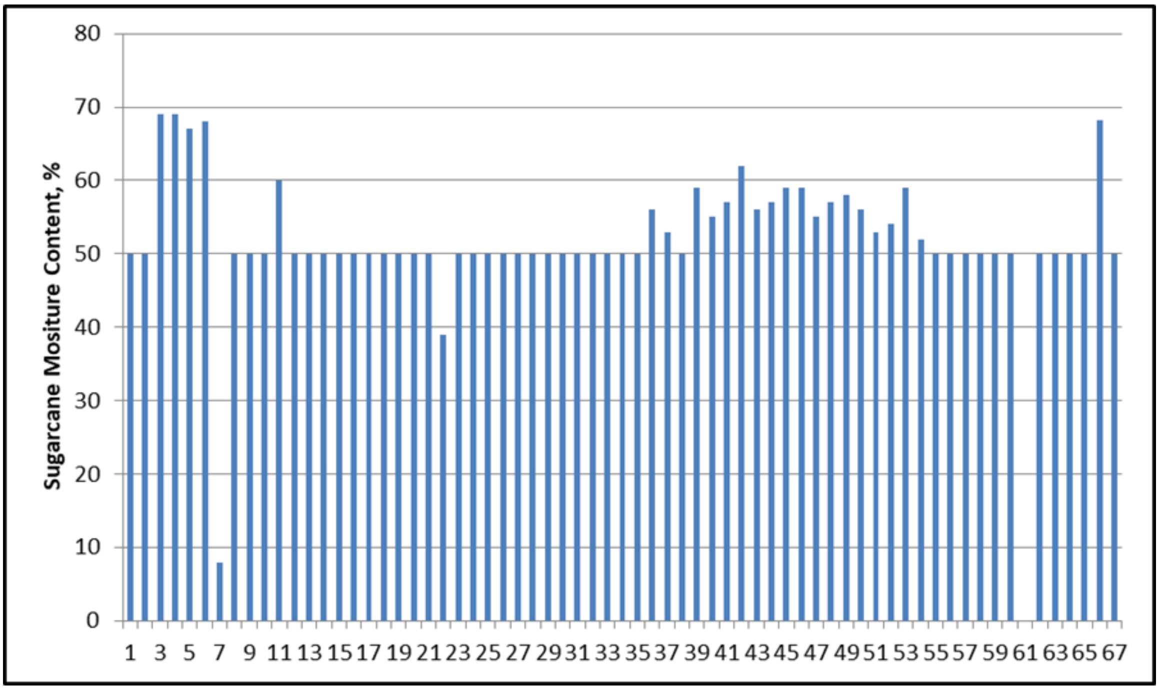

Figure 5 Sugarcane Moisture Content

Soil Amendments

Three soil amendments are included in the RenovaBio calculator, two types of limestone (dolomite and calcite) and gypsum (calcium sulfate dehydrate). Fifty-nine operations reported non-default values for limestone and gypsum additions. The default values in the calculator are 12 kg/tonne for dolomite limestone plus 5 kg/tonne of gypsum. The weighted average application rate for dolomite limestone was 10.44 kg/tonne of cane. In addition, the average rate of gypsum addition was 4.26 kg/tonne of cane. The results are shown in Table 2.

Table 2 Soil Amendment Application Rates

	Kg/tonne of sugar cane	Number of respondents	Standard Deviation
Calcite Limestone	0.04	5	2.9
Dolomite limestone	10.40	58	4.0
Gypsum	4.26	55	2.9
Total	14.70	59	6.6

The individual rates for total amendments for the producers are shown in Figure 6.

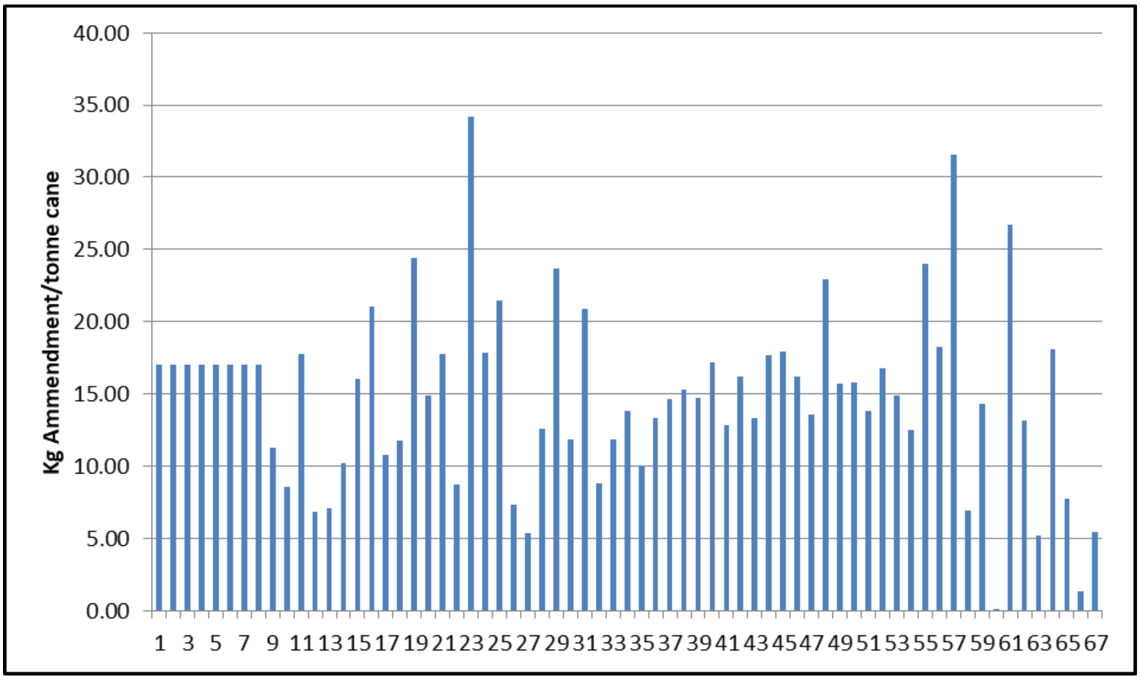

Figure 6 Total Amendments per Tonne of Sugarcane

The individual rates for the dolomite limestone for the producers are shown in Figure 7.

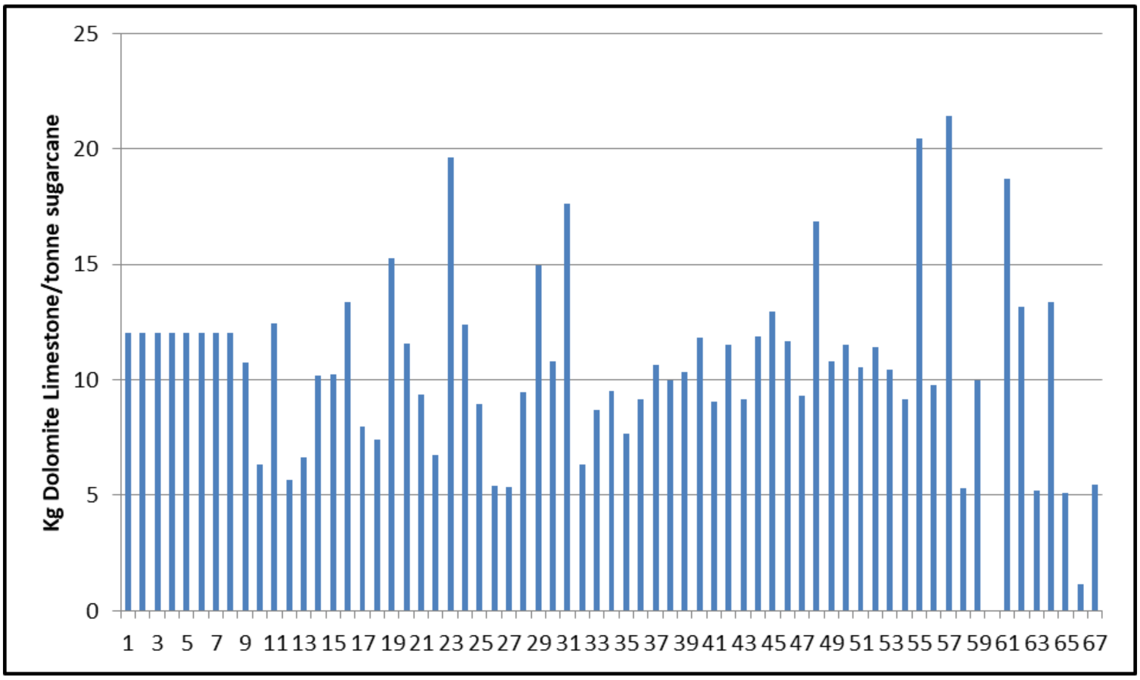

Figure 7 Kilograms Dolomite Limestone per Tonne of Sugarcane

The individual rates for the gypsum for the producers are shown in Figure 8.

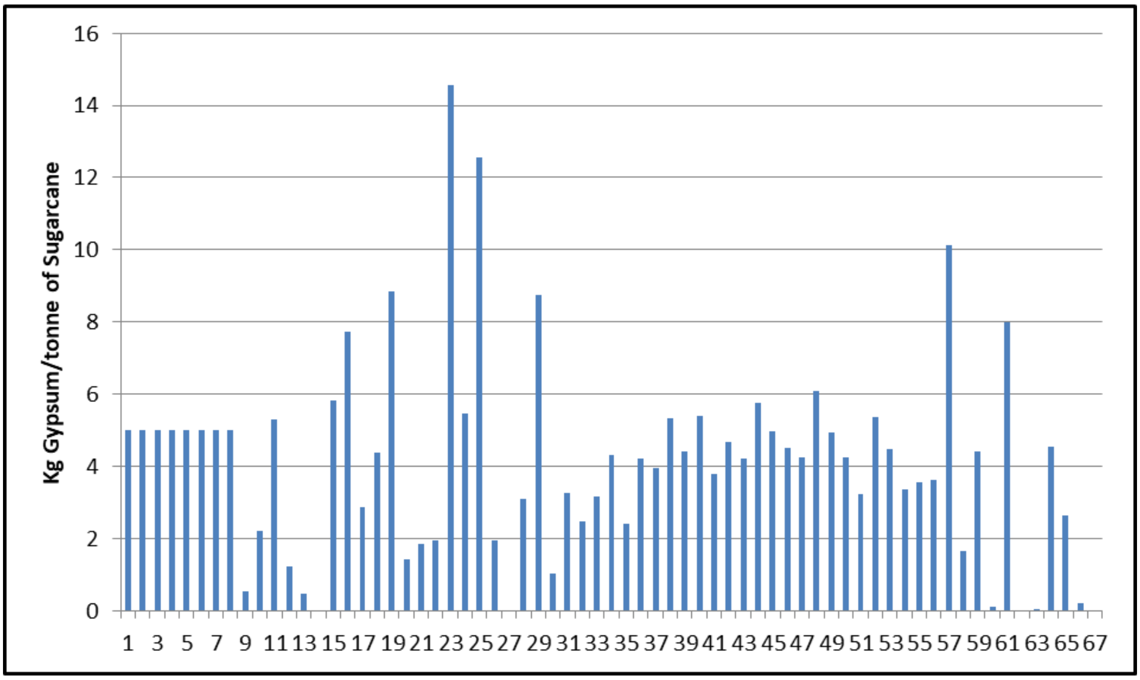

Figure 8 Kilograms Gypsum per Tonne of Sugarcane

Finally the information on the calcite limestone, which is only used by a few producers, is shown in Figure 9

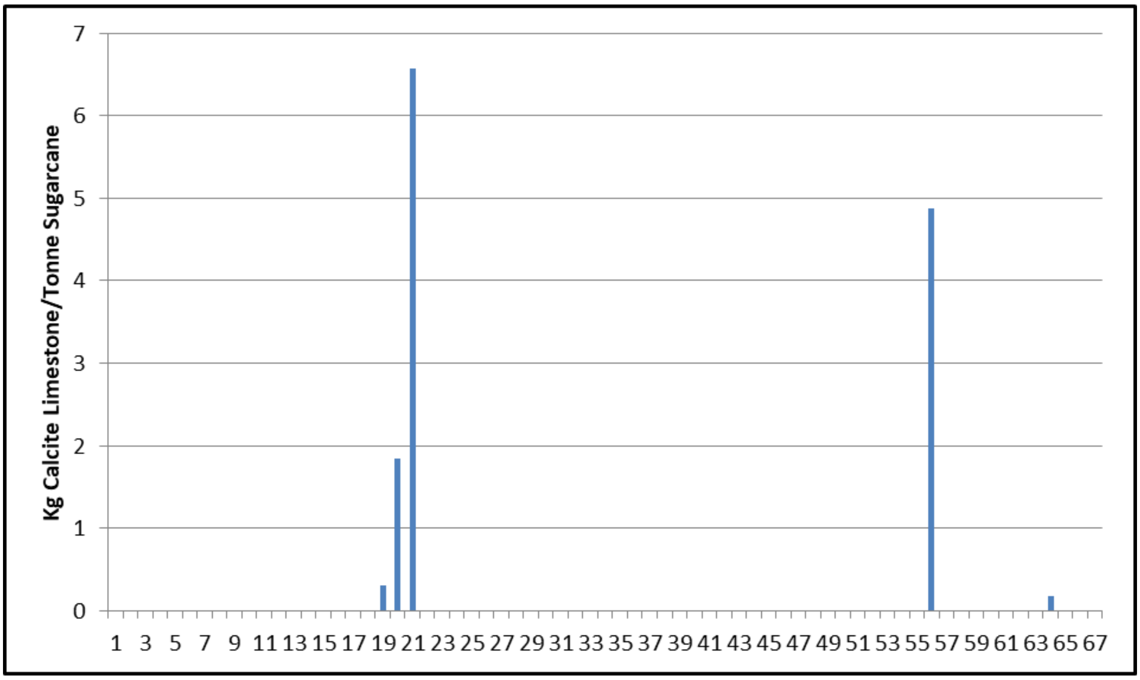

Figure 9 Kilograms Calcite Limestone per Tonne of Sugarcane

Fertilizer

There is a significant amount of information available on fertilizer rates and types of fertilizer used by the producers. There is information on synthetic fertilizers and on organic fertilizers, although in the case of some of the specific organic fertilizers applied a number of producers relied on default values for the nitrogen concentrations for the products applied.

SYNTHETIC FERTILIZERS

A wide range of synthetic fertilizers were reported and there were some that included "other" types of fertilizer families. Eight of the 67 producers used the default values of 2 kg N/tonne, 1 kg P2O5/tonne, and 2 kg K2O/tonne. The data from the mills that used actual values rather than default values is shown Table 3.

Table 3 Synthetic Fertilizer Application Rates

	Kg/tonne of sugar cane	Number	Standard Deviation
Urea, kg N/tonne	0.78	57	0.42
Monoammonium Phosphate (MAP), kg N/t cane	0.05	47	0.05
Diammonium Phosphate (MAP), kg N/t cane	0.00	2	0.01
Ammonium Nitrate, kg N/tonne	0.28	44	0.21
UAN, kg N/tonne	0.00	6	0.14
Ammonia Sulphate, kg N/tonne	0.05	16	0.58
Calcium Ammonia Nitrate, kg N/t	0.01	4	0.15
Monoammonium Phosphate (MAP), kg P_2O_5/tonne	0.24	51	0.26
Diammonium Phosphate (MAP), kg P_2O_5/tonne	0.00	2	0.78
Simple superphosphate (SSP), kg P_2O_5/tonne	0.27	51	0.19
Triple superphosphate (TSP), kg P_2O_5/tonne	0.00	4	0.07
Potash, kg K_2O/tonne	1.01	56	0.56
Other N, kg N/tonne	0.16	22	0.38
Other P_2O_5, kg P_2O_5/tonne	0.10	43	0.22
Other K_2O, kg K2O/tonne	0.21	24	0.48
Total N, kg N/tonne	1.33	59	0.35
Total P, kg P2O5/tonne	0.61	59	0.37
Total K, kg K2O/tonne	1.22	59	0.39

The variation in the total N application rates for all mills (including those using default values) is shown in Figure 10. Only one producer used more that the default value.

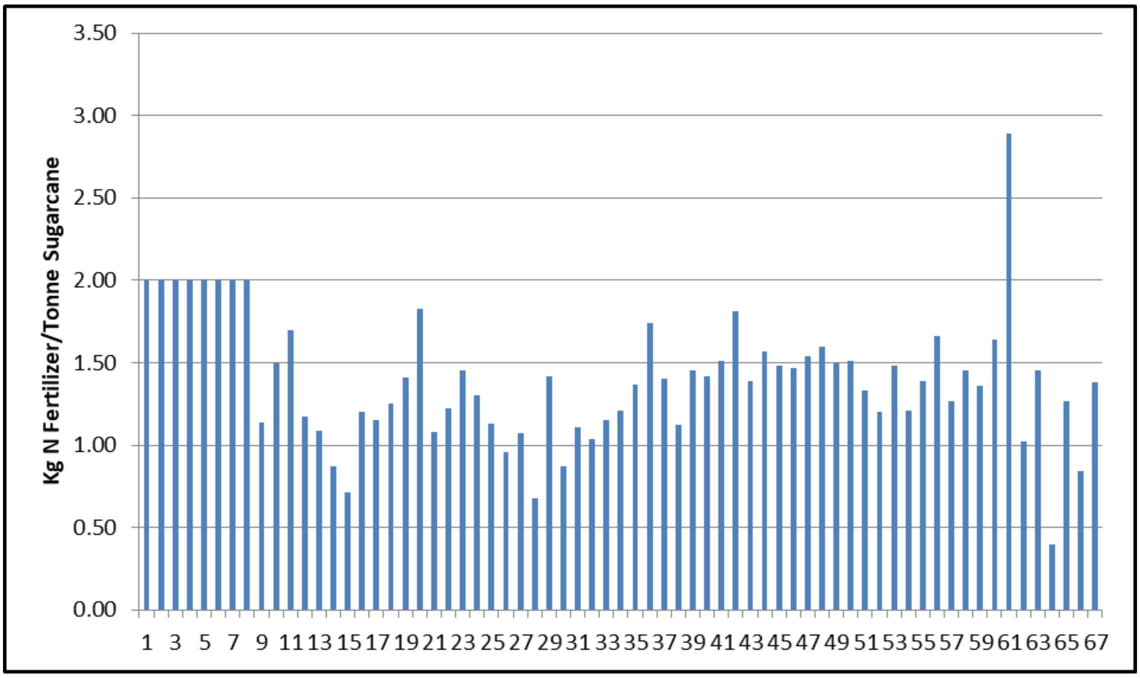

Figure 10 Kilograms Synthetic Nitrogen Fertilizer per Tonne of Sugarcane

The variation in the total N application rates for all mills (including those using default values) is shown in Figure 11. Here six producers used more that the default value.

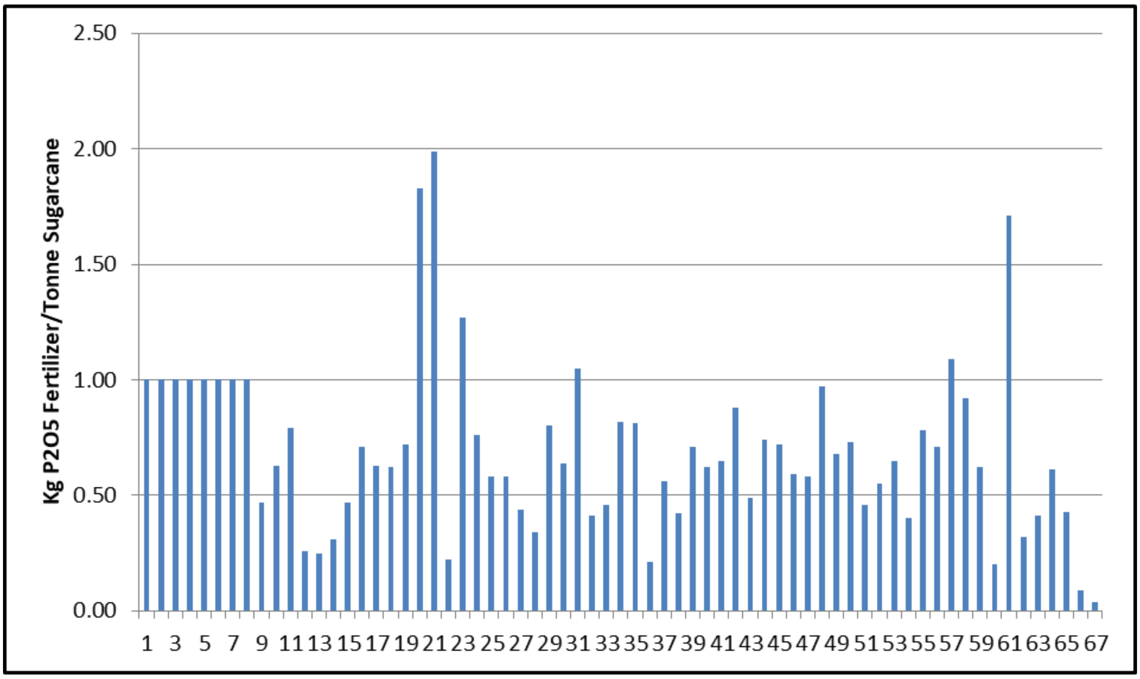

Figure 11 Kilograms Phosphate Fertilizer per Tonne of Sugarcane

The variation in the total K application rates for all mills (including those using default values) is shown in Figure 12. Here three producers used more that the default value.

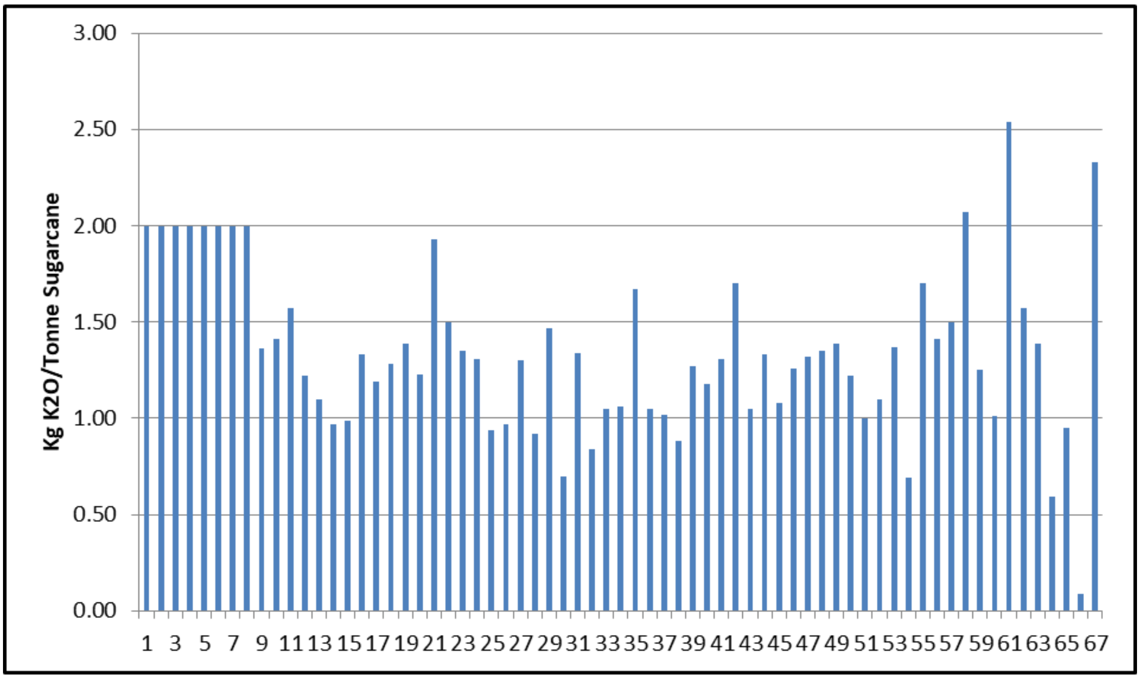

Figure 12 Kilograms Potash Fertilizer per Tonne of Sugarcane

ORGANIC FERTILIZERS

The mills reported the quantity of vinasse, filter cake, ash and soot, and the potential to enter two additional organic fertilizers. There were default values provided for the vinasse application rate (1,000 litres/tonne sugarcane), nitrogen concentration of the vinasse (0.28 g N/litre vinasse), filter cake application rate (42.8 kg (wet)/tonne of sugarcane), filter cake nitrogen concentration (2.8 g N/kg filter cake), and the ash and soot application rate (10.08 kg (wet) per tonne of sugar cane) but not for the nitrogen content of the ash. Most respondents used the default values for the nitrogen concentration. There were a few respondents who reported “other” organic fertilizers. About 75% of the organic nitrogen fertilizer was from the vinasse. The collected data is summarized in Table 4.

Table 4 Organic Fertilizer Application Rates

	Kg/tonne of sugar cane	Number	Standard Deviation
Vinasse, litres/tonne	1,059	59	1,703
Concentration, g n/litre	0.36	59	0.13
kg n/tonne	0.31	59	0.13
Filter cake Wet basis	28.7	57	13.00
Concentration, g n/kg	2.90	57	2.22
kg n/tonne	0.08	59	0.09
Ash and soot (wet basis)	8.19	52	8.89
Concentration, g n/kg	0.65	17	6.97
kg n/tonne	0.01	17	0.07
Other, kg/tonne cane	1.71	13	5.50
Concentration, g n/kg	3.42	13	11.04
kg n/tonne	0.01	11	0.08
Other, kg/tonne cane	0.00	4	0.22
Concentration, g n/kg	0.82	3	83.06
kg n/tonne	0.00	3	0.04
Total organic N	0.42	59	0.16

The variation in the organic nitrogen fertilizer application rates between the producers are shown in Figure 13. Sixteen producers applied more organic N fertilizer than the default value in the RenovaBio calculator.

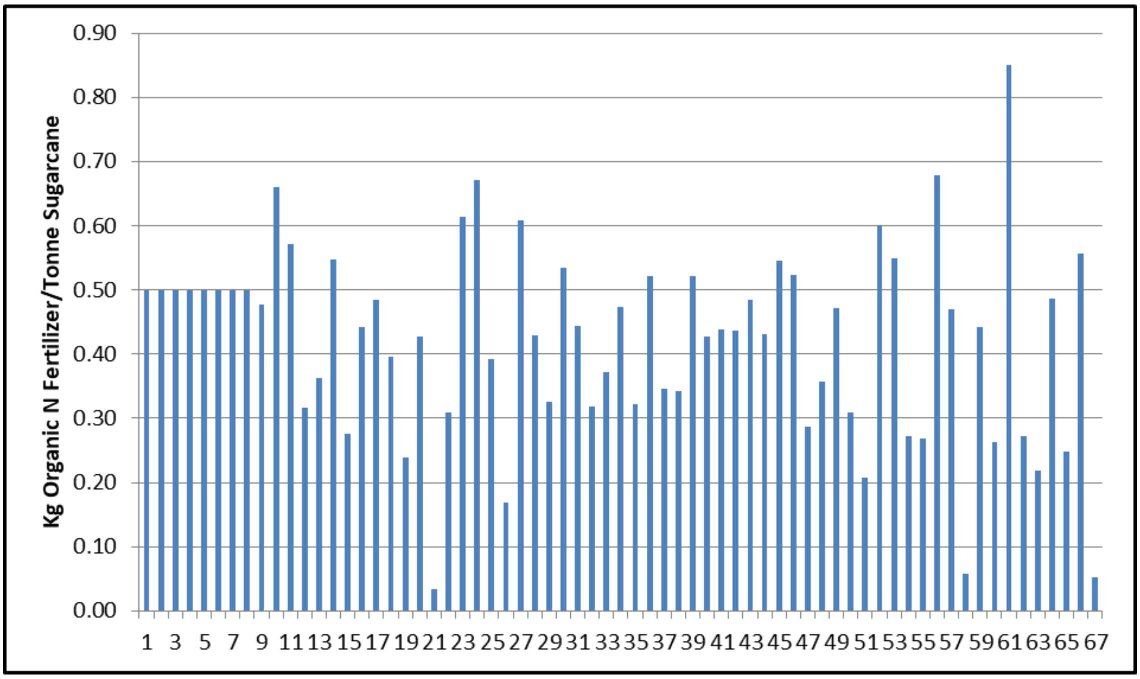

Figure 13 Kilograms Organic Nitrogen Fertilizer per Tonne of Sugarcane

NITROGEN SUMMARY

The nitrogen fertilizer is important because there are emissions associated with the production of the fertilizer and there are N2O emissions associated with the use of the fertilizer. The organic fertilizers will not have any production emissions but their use still contributes to the generation of N_2O emissions. Figure 14 shows the combined nitrogen fertilizer application rates. Only one producer applied more than the default values.

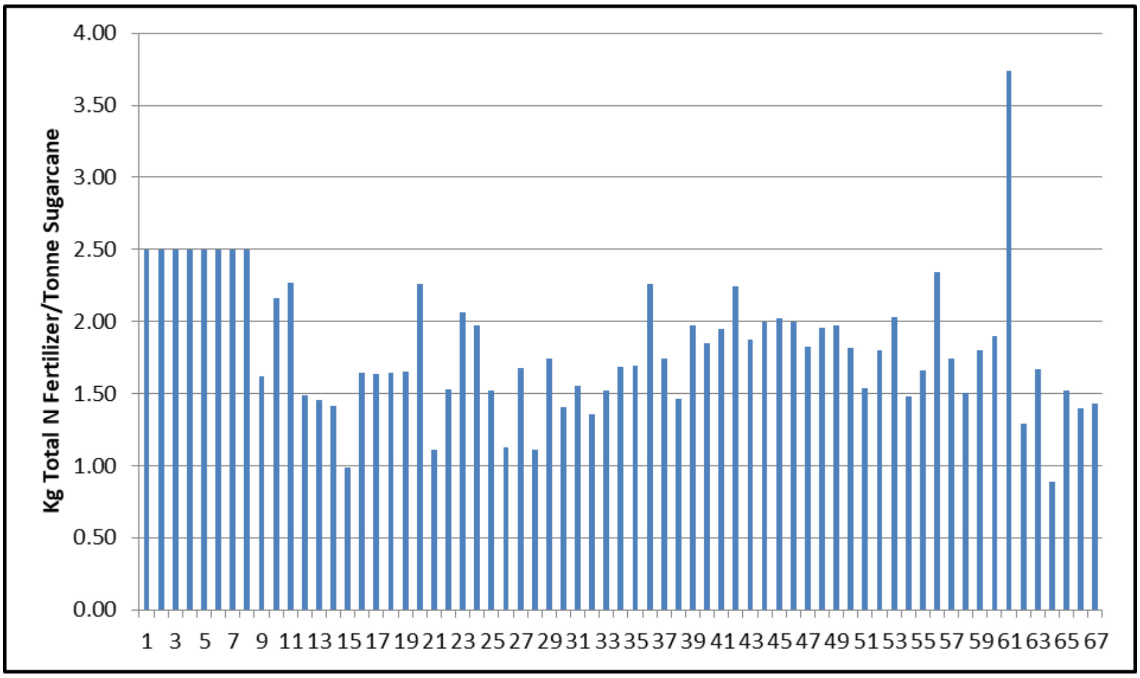

Figure 14 Kilograms Total Nitrogen Fertilizer per Tonne of Sugarcane

Energy Consumption

The producers reported the quantity of diesel fuel consumed and the percentage of biodiesel in the diesel fuel. The biodiesel percentage varied up to 11%. The quantity of gasoline and hydrous ethanol was also reported. The energy information is shown in Table 5. The energy consumption covers the field activities and the transportation of the sugarcane from the field to the mill. LCA models often calculate the fuel used for transportation separately from the fuel used for field activities. It is not possible to separate this information from the data set.

Table 5 Fuel Consumption

	Litres/tonne of sugar cane	Number	Standard Deviation
Diesel Fuel	4.51	59	1.25
Biodiesel	0.50	59	0.14
Gasoline	0.003	13	0.03
Hydrous Ethanol	0.17	57	0.09
Grid Power, kWh/tonne	0.68	16	6.77

DIESEL FUEL

The default value in the RenovaBio calculator was six litres of petroleum diesel fuel with 11% biodiesel per tonne of sugarcane produced. The eight producers who used default values for fertilizer application rates also chose to use default values for fuel use. Diesel fuel use by producer is shown in Figure 15. The default values for diesel fuel do not appear to be as conservative as the default values for fertilizer application rates. The producers did not have to report if they employed mechanical or manual harvesting.

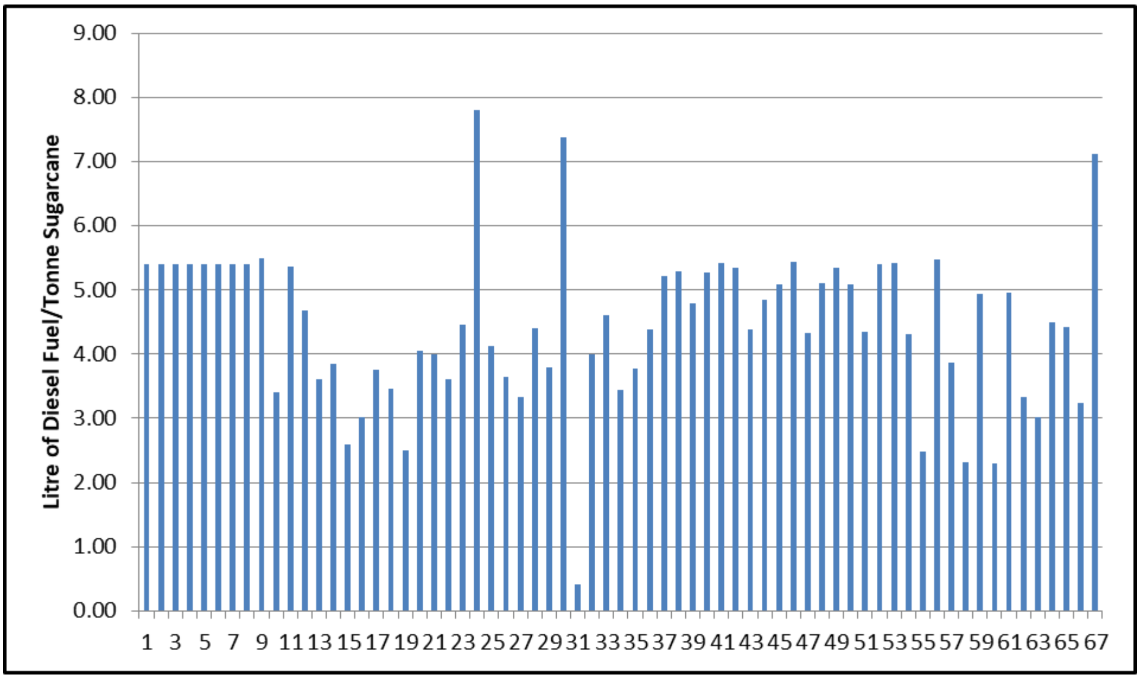

Figure 15 Litres of Diesel Fuel per Tonne of Sugarcane

BIODIESEL

All of the diesel fuel consumed contained some biodiesel. B8, B10, and B11 blends were reported. The biodiesel (as B100) used is shown in Figure 16.

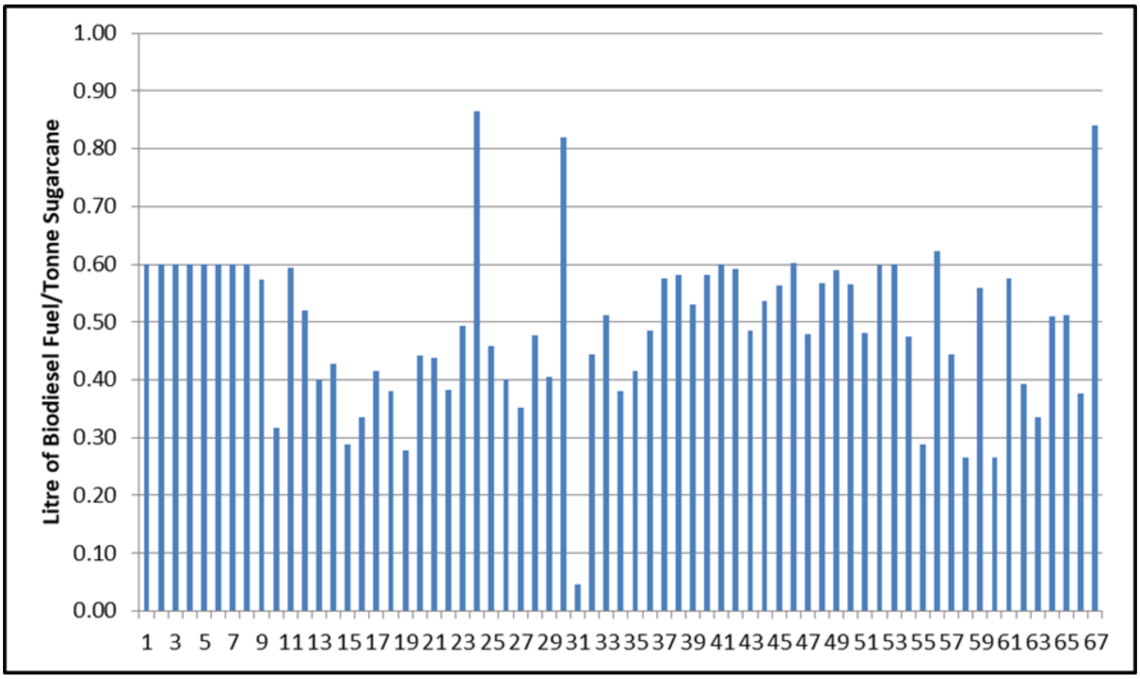

Figure 16 Litres of Biodiesel Fuel per Tonne of Sugarcane

GASOLINE

Gasoline consumption was reported by 13 producers and the average quantity used was very small. The information is shown in Figure 17. The gasoline would have contained the prescribed quantity of anhydrous ethanol.

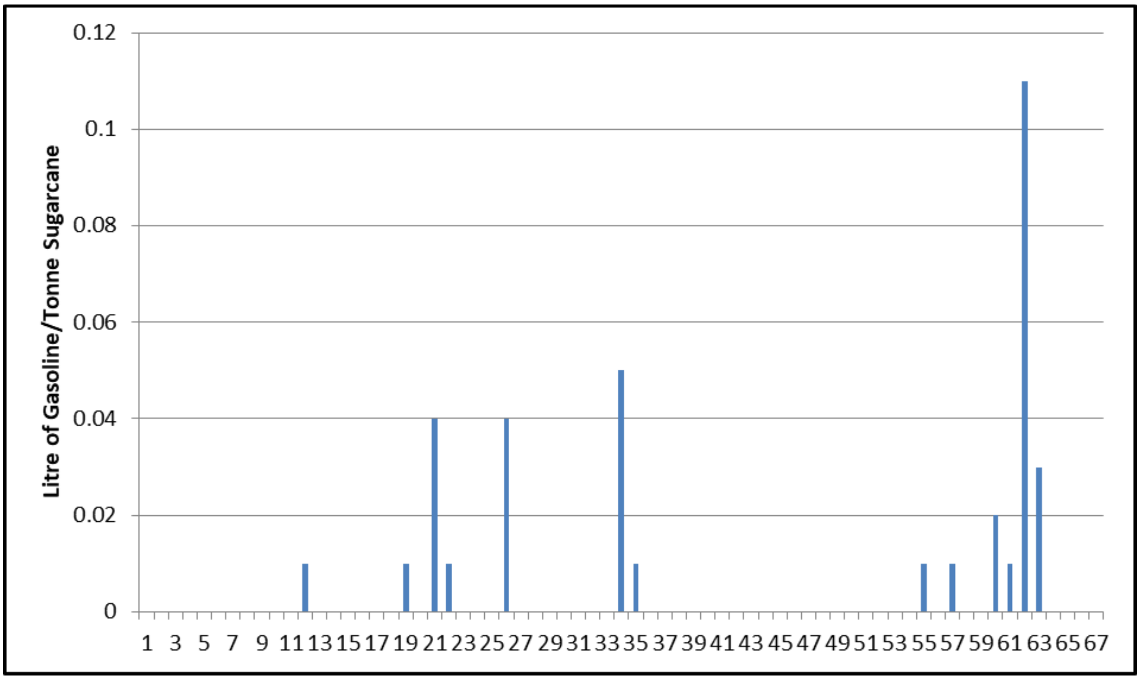

Figure 17 Litres of Gasoline Fuel per Tonne of Sugarcane

HYDROUS ETHANOL

There was use of hydrous ethanol reported by almost all of the producers who did not use the defaults values as shown in Figure 18.

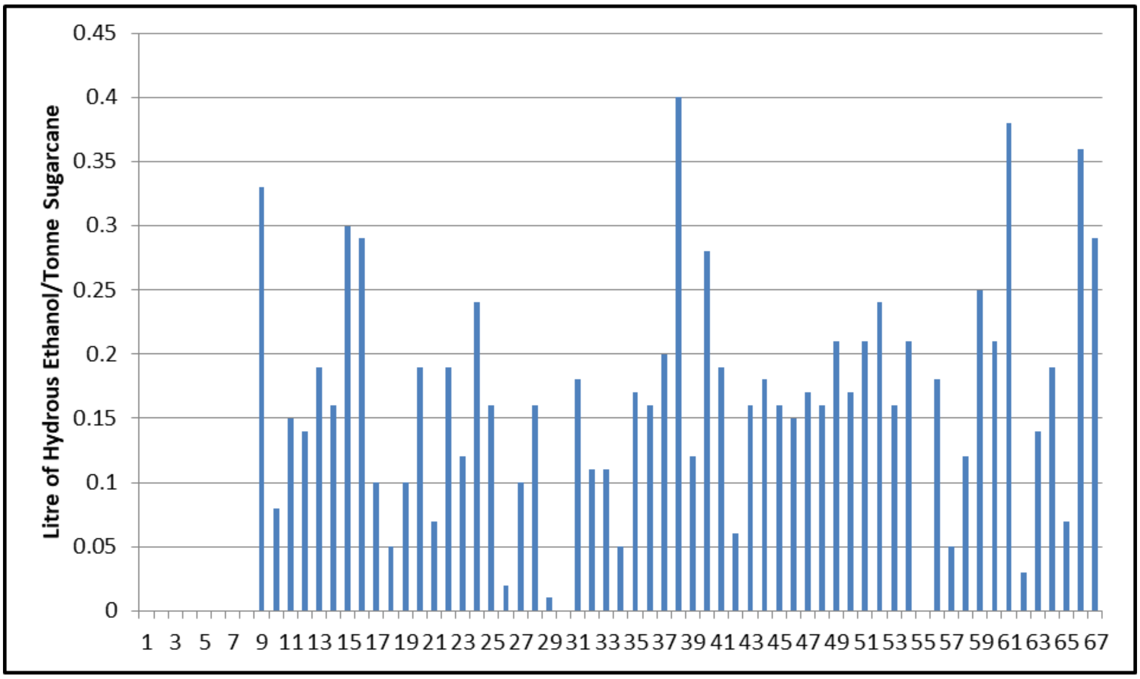

Figure 18 Litres of Hydrous Ethanol per Tonne of Sugarcane

GRID POWER

Some producers reported the use of grid electricity in the section of the RenovaBio related to energy use in harvesting. There are a few producers who consume significant quantities of grid power as shown in Figure 19.

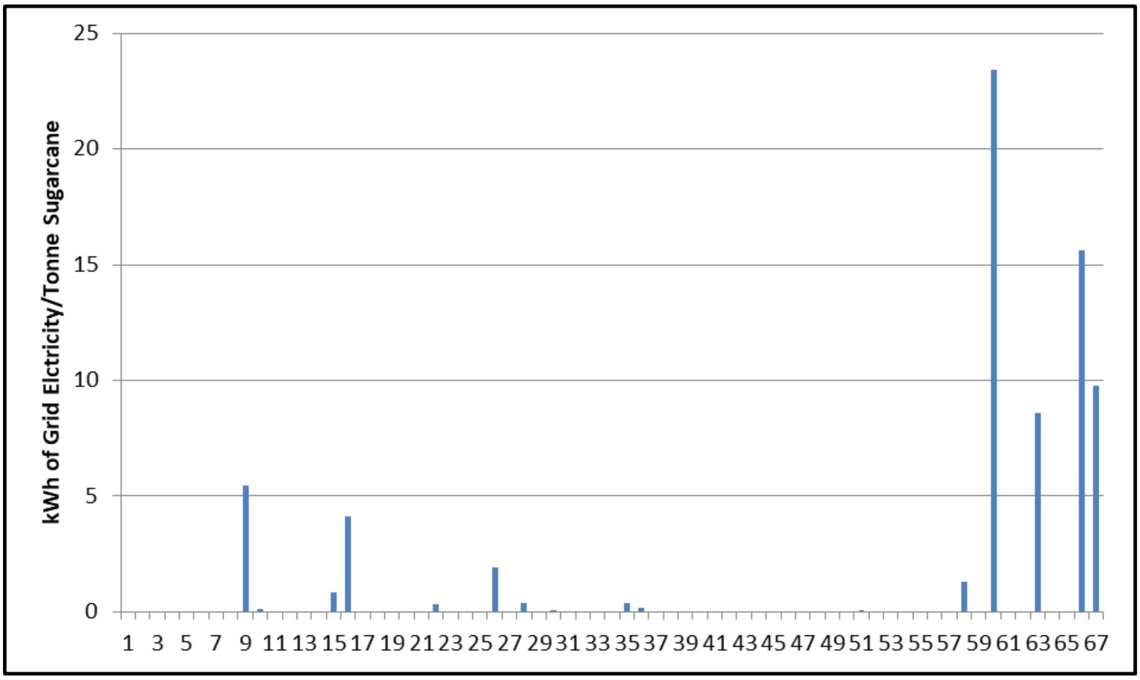

Figure 19 kWh Grid Electricity per Tonne of Sugarcane

Ethanol Production

Producers reported the quantity of sugarcane processed and in one case that included the quantity of sugarcane straw processed as the facility included some cellulosic ethanol production as well as sugarcane ethanol production. In most cases the quantity of sugarcane processed was the same as the quantity produced as the mills are usually integrated with the growing operations but there were a few cases where there were small differences indicating that some sugarcane was bought or sold.

Information was also supplied on the energy consumed in the sugarcane processing operations.

PRODUCTS PRODUCED

There was information supplied for each operation on the quantities of anhydrous ethanol, hydrous ethanol, sugar, electricity produced, and in some cases mills sold excess bagasse. Auditors looked for sales invoices to support the reported quantities. An anhydrous ethanol equivalent value is calculated by adding the anhydrous production, 95% of the hydrous production and 1.58 kg of sugar to produce one litre of ethanol. The information is summarized in Table 6.

Table 6 Products Produced

	Litres/tonne of sugar cane	Number	Standard Deviation
Anhydrous ethanol	14.26	42	18.69
Hydrous ethanol	35.67	66	27.48
Sugar, kg	48.68	51	21.88
Electricity, kWh/tonne	29.89	35	27.33
Bagasse, kg (wet)/tonne	9.13	39	16.55
Anhydrous equivalent	80.03	67	11.82

Anhydrous Ethanol

About two thirds of the mills produced anhydrous ethanol, although only one of the producers produced anhydrous ethanol exclusively. The individual results are shown in Figure 20.

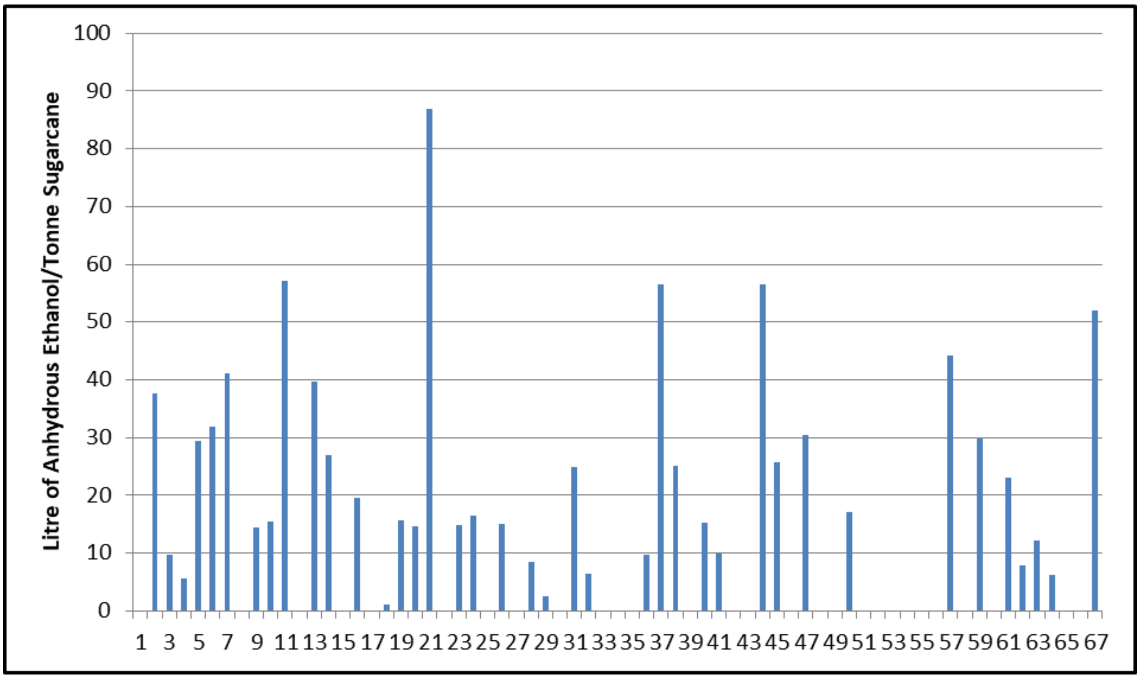

Figure 20 Litres of Anhydrous Ethanol per Tonne of Sugarcane

Hydrous Ethanol

All but one mill produced some hydrous ethanol. There was one mill that had a very high yield. This mill was very small and has minimal impact on the average value. The individual data is shown in Figure 21.

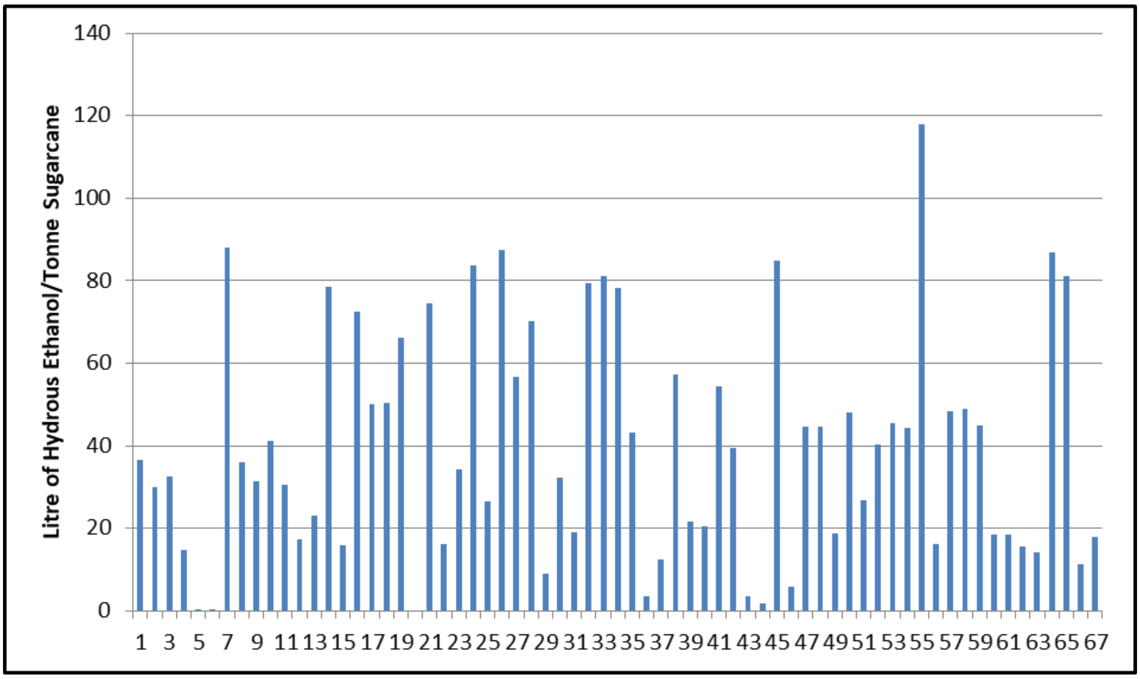

Figure 21 Litres of Hydrous Ethanol per Tonne of Sugarcane

Sugar Yield

A number of mills produce sugar in addition to ethanol. The kilogram of sugar produced per tonne of sugarcane is shown in Figure 22.

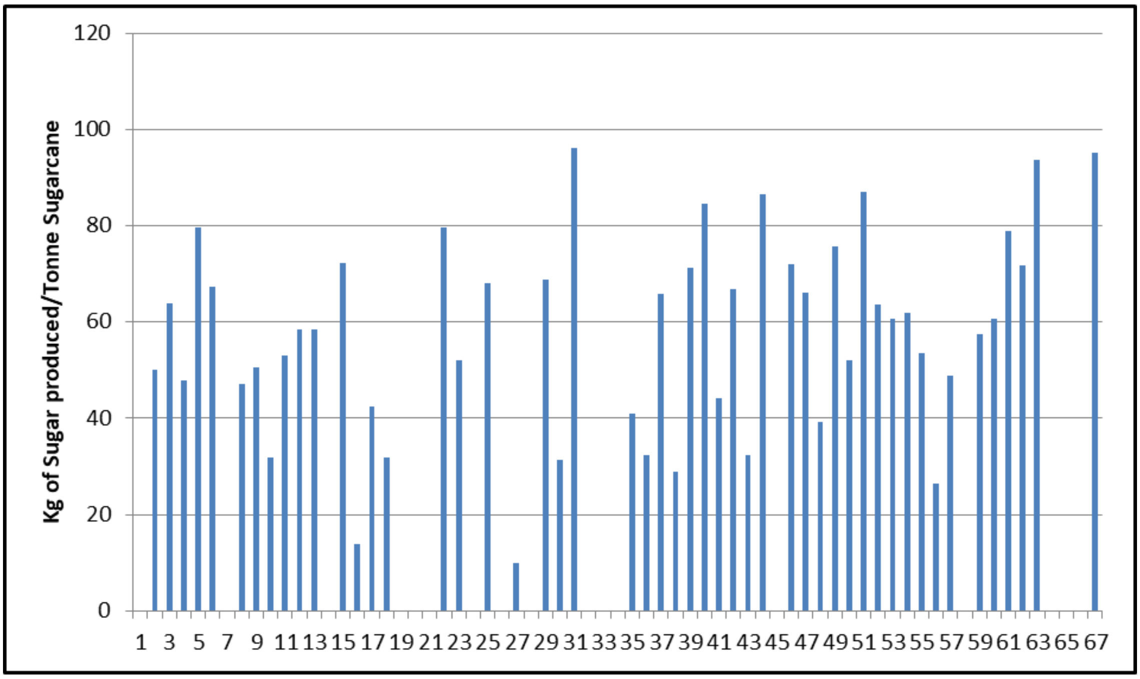

Figure 22 Kilograms of Sugar per Tonne of Sugarcane

Effective Anhydrous Yield

When all of the products are converted to a common metric (An anhydrous ethanol equivalent value is calculated by adding the anhydrous production, 95% of the hydrous production and 1.58 kg of sugar to produce one litre of ethanol) there is much less variation in the output. There are still two mills that do look like outliers. As noted earlier the mill with the highest reported yield is very small, the mill with the second highest yield was also smaller than average and represents less than 1% of the sugarcane processed. Figure 23 presents the results.

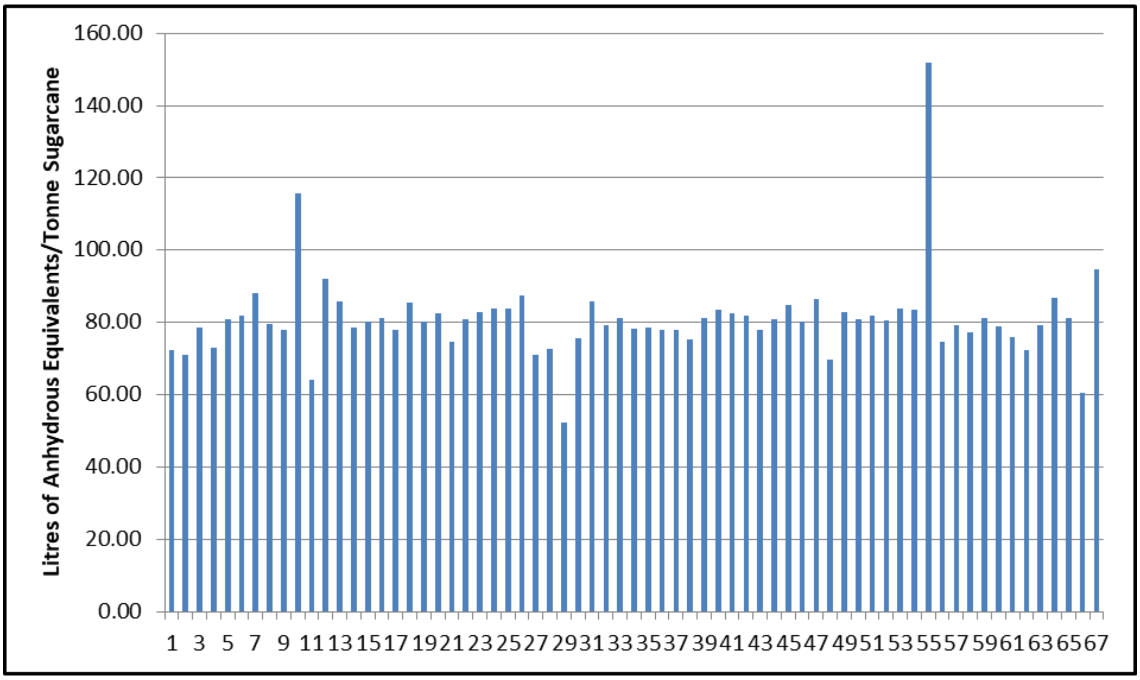

Figure 23 Anhydrous Ethanol Equivalents per Tonne of Sugarcane

Electricity Yield

Slightly more than 50% of the mills also include electricity as an exported product. The quantity of power exported varies significantly as shown in Figure 24.

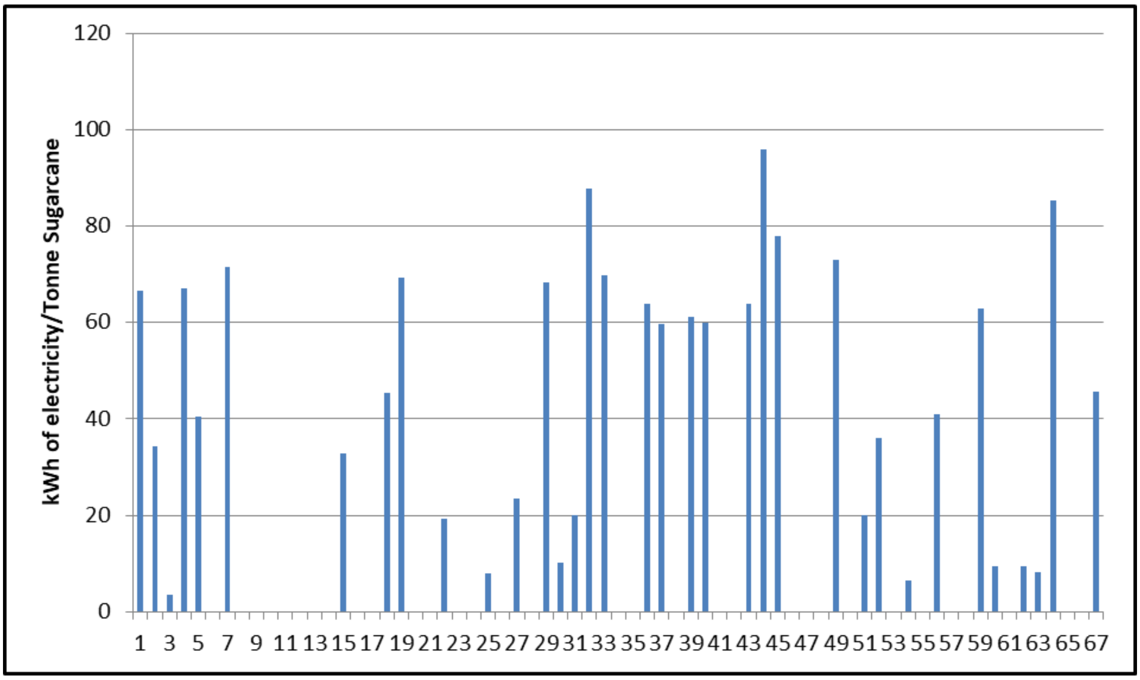

Figure 24 kWh of Electricity Exported per Tonne of Sugarcane

Bagasse Sold

Thirty-nine mills sold excess bagasse. This might have been sold to other mills, as some mills report purchasing bagasse, or it could have been sold to other facilities with biomass boilers.

The quantities sold by individual mills are shown in Figure 25.

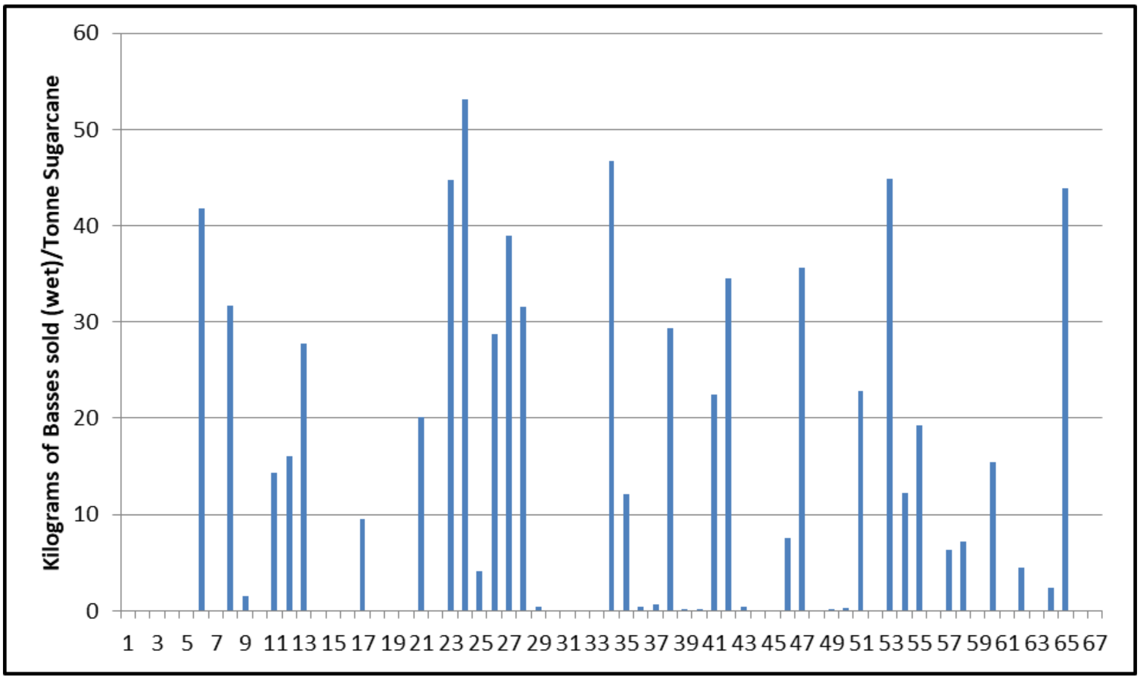

Figure 25 Kilograms of Bagasse Sold per Tonne of Sugarcane

ENERGY CONSUMED

Most of the energy for the mills is supplied by their own bagasse but there are a few other sources of purchased energy as shown in Table 7.

Table 7 Energy Consumed

	Value	Number	Standard Deviation
Bagasse, kg (wet)/tonne sugarcane	242.2	65	52.54
Bagasse moisture content, %	50.9	64	1.05
Third party Bagasse, kg (wet)/tonne sugarcane	23.43	25	38.08
Third party Bagasse, moisture content, %	47.0	25	4.4
Third party Bagasse, transportation distance, km	55	25	152
Other biomass, kg (wet)/tonne sugarcane	1.58	23	4.42
Other biomass, kg (dry)/tonne sugarcane	1.08	23	4.47
Fuel oil, litre/tonne sugarcane	0.06	37	0.59
Own hydrous ethanol, litre/tonne sugarcane	0.01	31	0.09
Grid Power, kWh/tonne sugarcane	1.14	66	1.24

Own Bagasse

Bagasse is the fibrous material that remains after crushing sugarcane to extract their juice. It is burned at the mills to produce the energy for the facilities and to dispose of the material. All but one facility reported the quantity combusted as shown in Figure 26.

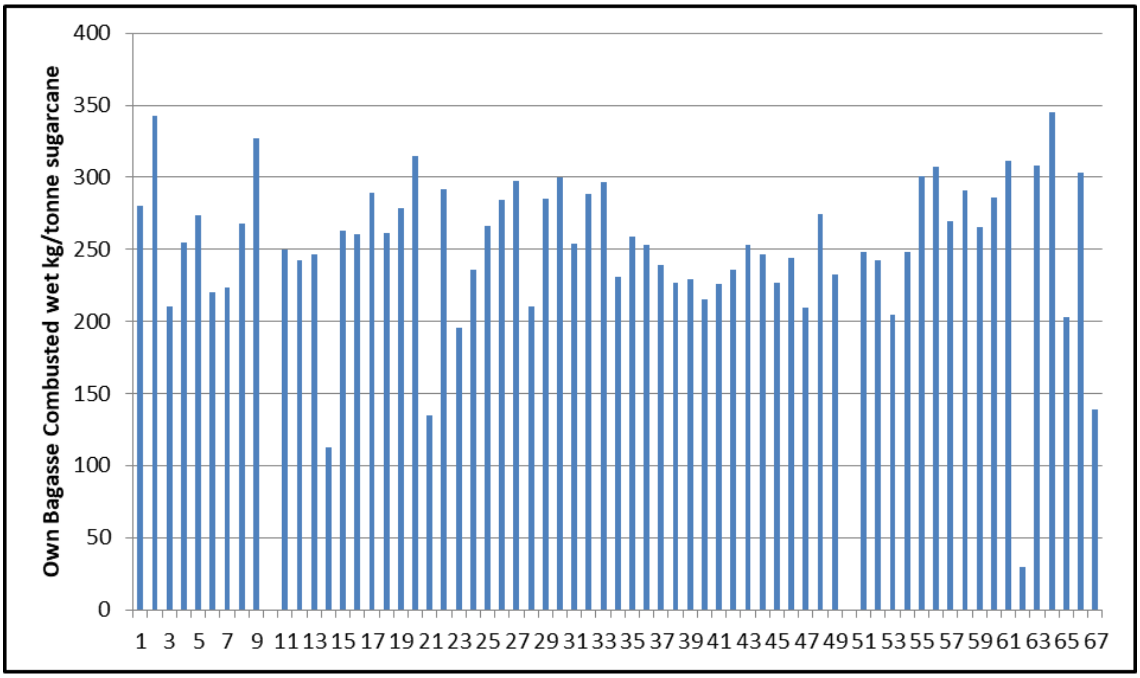

Figure 26 Kilograms of Own Bagasse Combusted per Tonne of Sugarcane

Third Party Bagasse

Some facilities purchase third party bagasse to supplement their own supply. Twenty-five mills reported purchases of bagasse from outside parties. In about one half of these cases, the purchases are small but the quantities are significant for the other mills as shown in Figure 27.

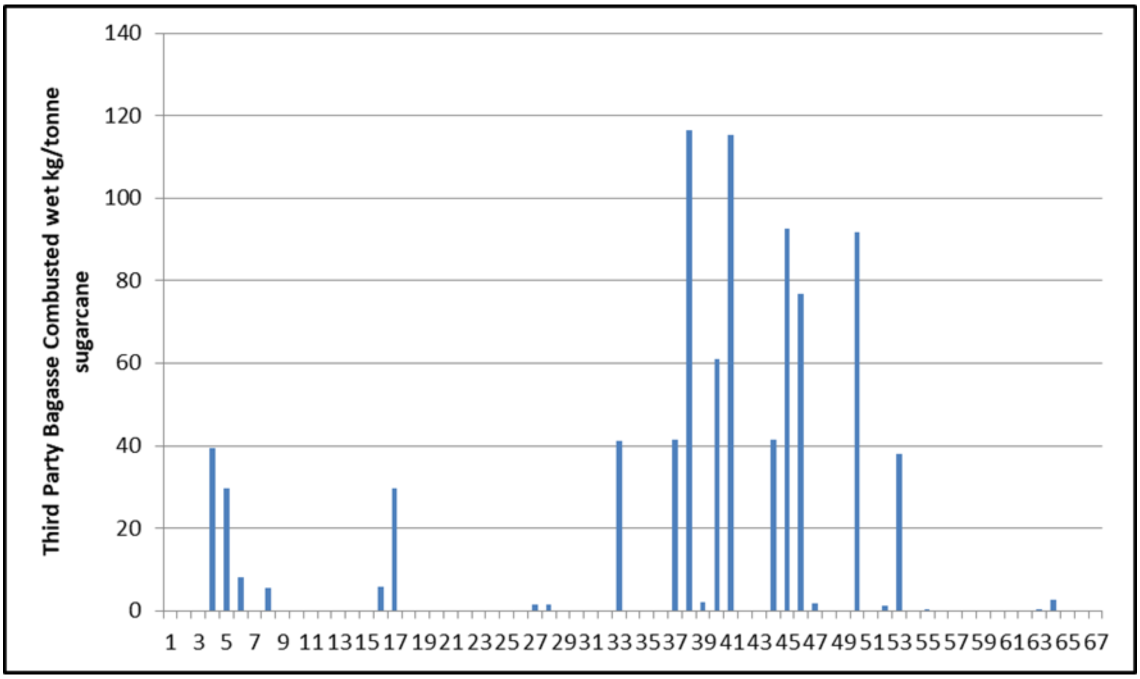

Figure 27 Kilograms of Third Party Bagasse Combusted per Tonne of Sugarcane

The transportation distance for the third party bagasse averaged 55 km, but one mill reported a value of more than 800 km, which results in a high standard deviation. The individual mill distances are shown in Figure 28.

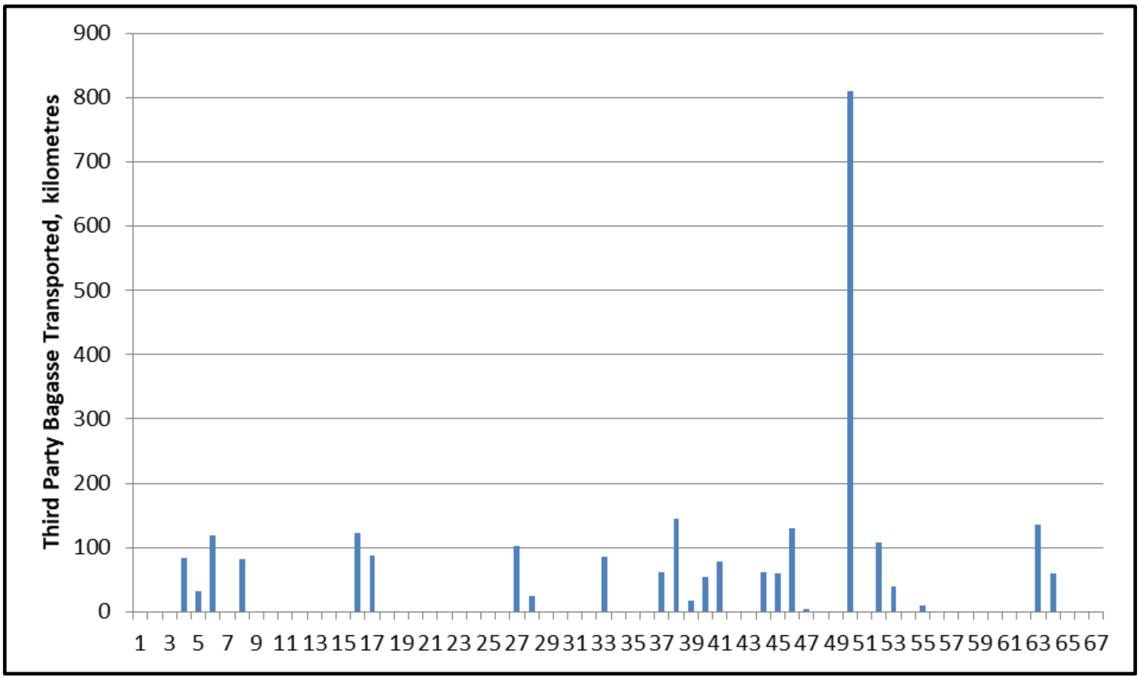

Figure 28 Kilometres of Third Party Bagasse Transported

Purchased Biomass

Small quantities of other biomass purchases were also reported. This includes their own straw (4 mills), third party straw (2 mills), wood chips 6 mills), firewood (16 mills), and forest residues (1 mill). Twenty four mills purchase some biomass other than bagasse but the average quantity purchased is only 1.7 wet kilograms (1.1 dry kilograms) per tonne of sugarcane processed. This includes their own straw for which the transportation energy consumption is already included in the production energy use. The average transportation distance for the non-straw biomass was only 3 km. The individual quantities purchased are shown in Figure 29.

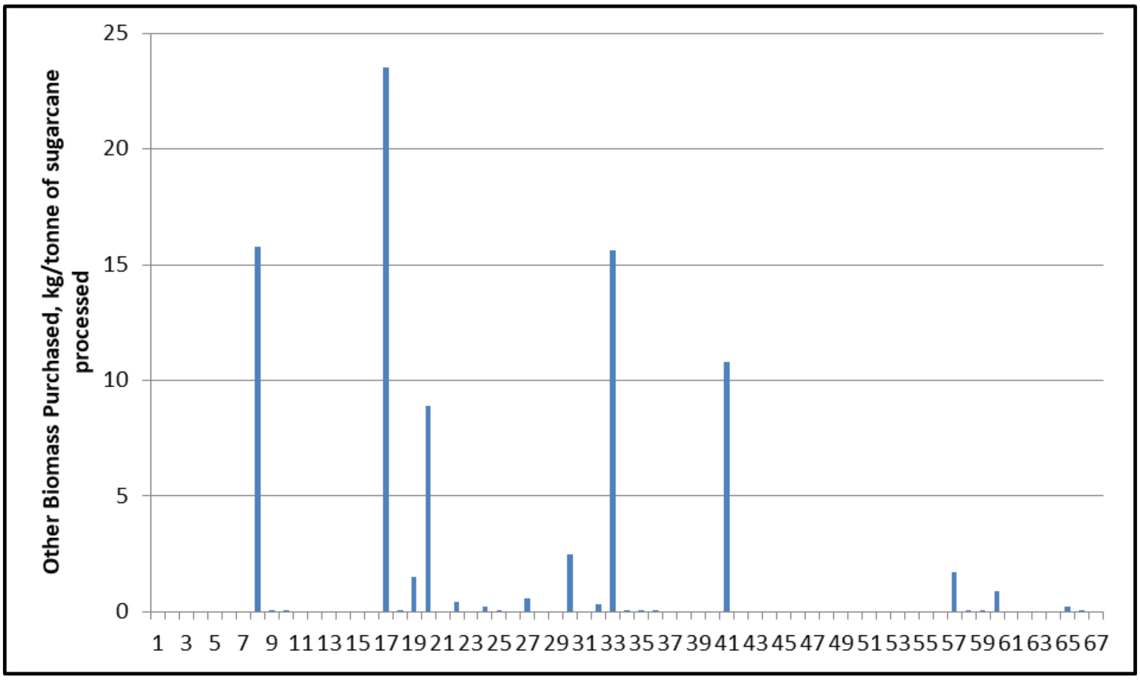

Figure 29 Other Biomass Purchased

Fuel Oil

A little more than one half of the mills reported using fuel oil in the processing operations. One mill is an outlier in terms of its consumption rate as shown in Figure 30.

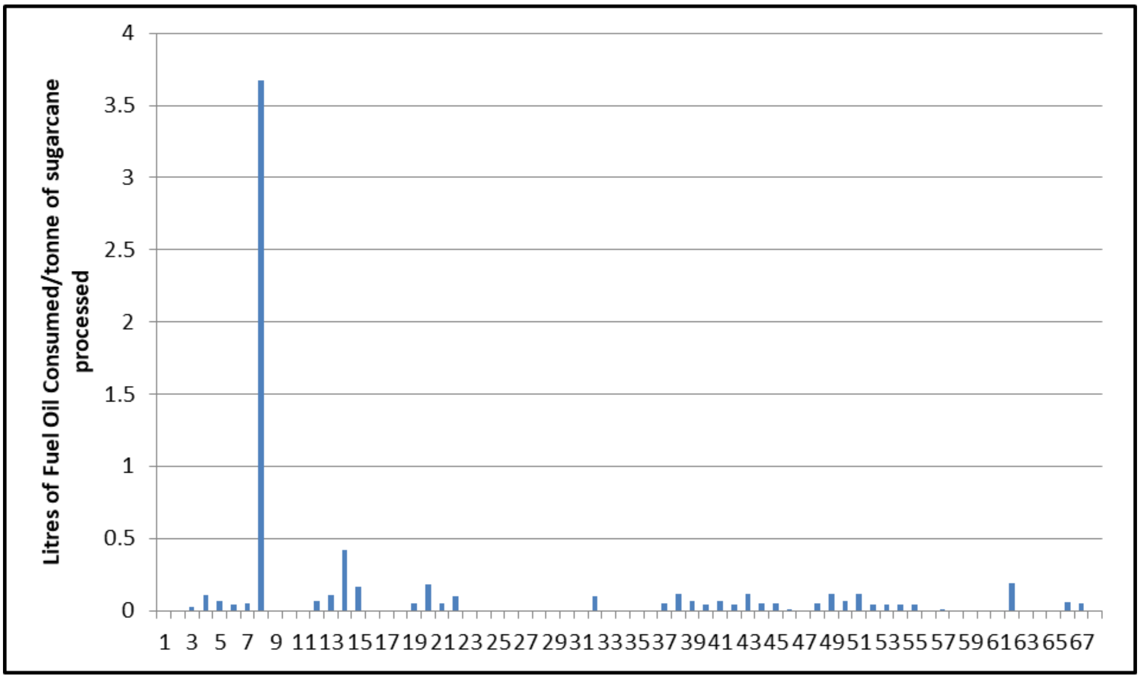

Figure 30 Fuel oil Combusted per Tonne of Sugarcane Processed

Own Hydrous Ethanol

Almost half of the mills reported some use of their own hydrous ethanol in the processing operations. Since the reported production of hydrous ethanol was supported by sales invoices it is likely that the own consumption of hydrous ethanol was not included in the production of hydrous ethanol. In most cases the volumes were small as shown in Figure 32.

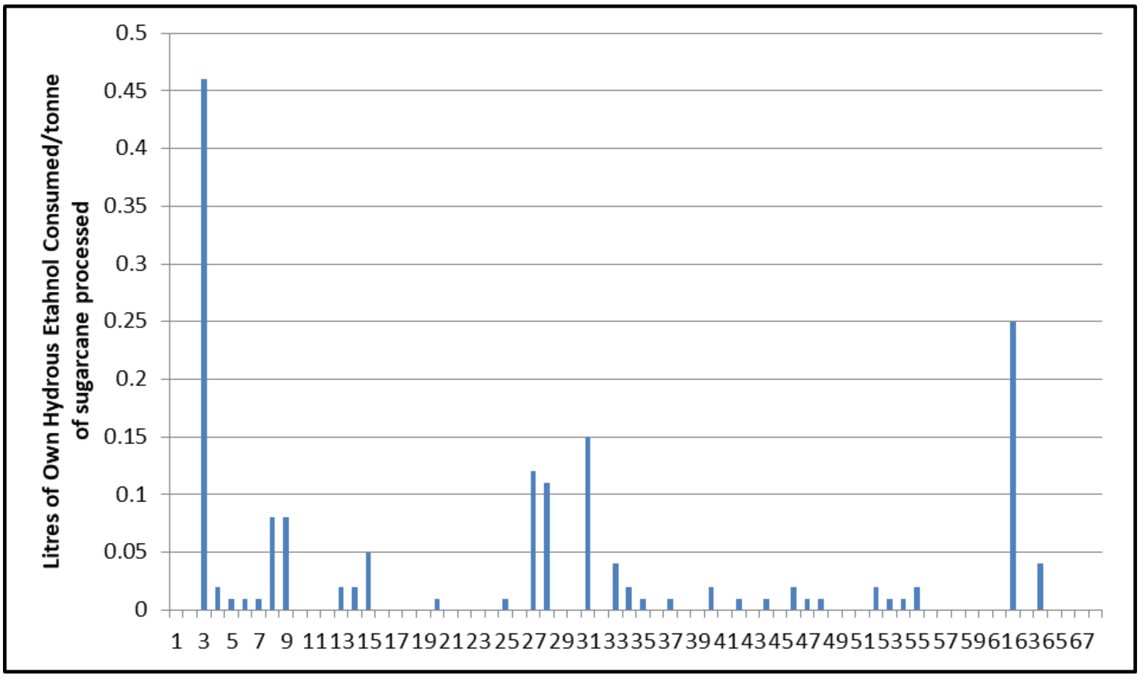

Figure 31 Own Hydrous Ethanol Consumed per Tonne of Sugarcane Processed

Purchased Electricity

All but one mill reported purchased electricity from the grid. There is significant variation in the quantity purchase as shown in Figure 32.

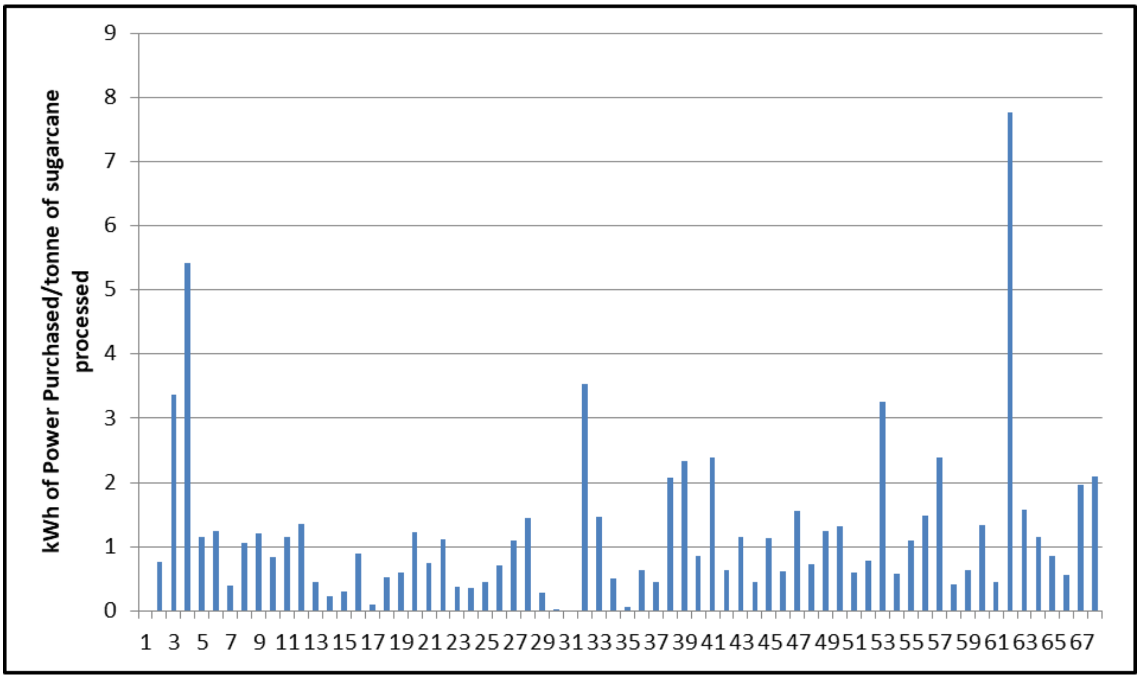

Figure 32 Grid Power Purchased per Tonne of Sugarcane Processed

RenovaBio Carbon Intensity

The RenovaBio calculator uses the input data presented in this report and calculates the carbon intensity for the operation. The calculated emissions may be used as a check on the emissions reported in other models.

These emissions are calculated using the GWPs from the IPCC 5th Assessment report. They use the 100 year GWPs without feedback. The emissions are presented using the lower heating value of ethanol.

The ethanol transportation emissions were calculated as part of the RenovaBio certification process, but those emissions are not included here.

The emission factors for fertilizers and chemicals were mostly taken from version 3.1 of the ecoinvent database. The N_2O emissions are calculated using the IPCC Tier 1 methodology and the calculator uses 1.12 kg N/tonne of sugarcane for the nitrogen content of the crop residues.

FARMING EMISSIONS

The emissions calculated for sugarcane production are shown in Figure 33. The weighted average value for mills that did not use default values in the calculator was 23.2 g CO_2eq/MJ. It is not stated with set of GWPs are used nor if the results are presented on a higher or lower heating value basis. This value is higher than is found in some other models. The gasoline comparator is 87.2 g CO_2eq/MJ.

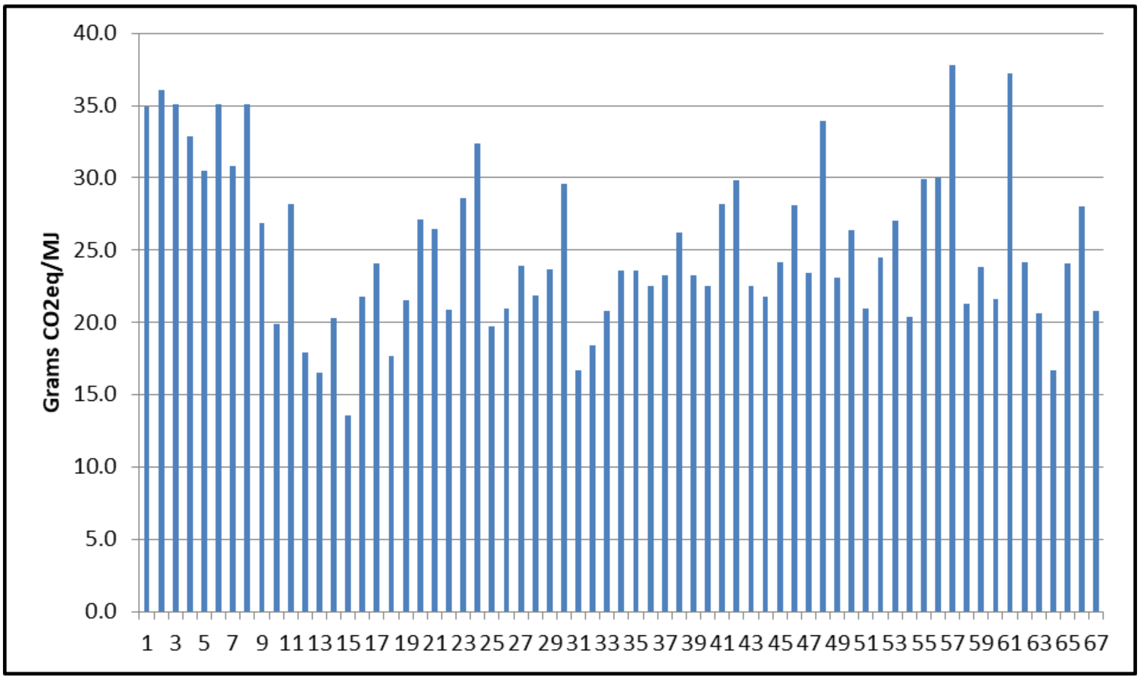

Figure 33 Sugarcane Production Emissions

PRODUCTION EMISSIONS

The calculated ethanol production emissions are shown in Figure 34. The average value was

1.3 g CO_2eq/MJ. The one outlier was the operation that was an outlier with respect to the quantity of fuel oil that was reported to be consumed.

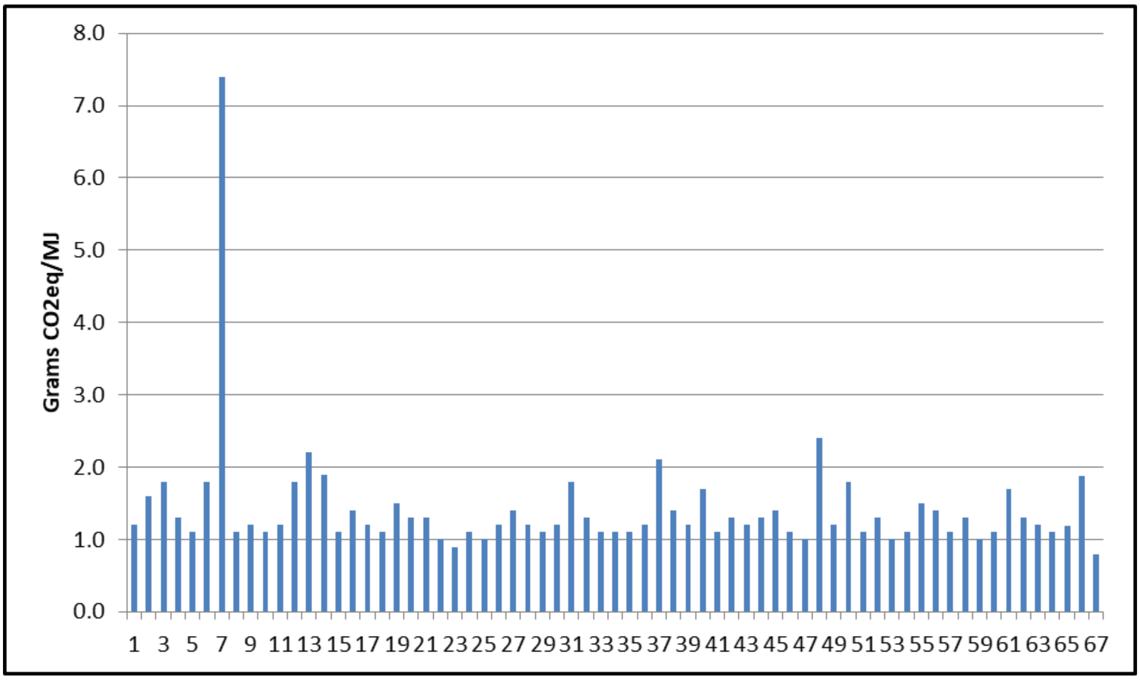

Figure 34 Ethanol Production Emissions

Discussion

It was not the goal of this work to analyze the emissions calculated by the RenovaBio program but there are a few observations from the dataset that are of interest. Figure 1Figure 35 compares the reported emissions with the quantity of nitrogen fertilizer applied. With many agricultural crops the N_2O emissions from the applied fertilizer and crop residues account for a large percentage of the carbon intensity. That is the case here as increasing the N fertilizer rate by one kg/tonne of sugarcane increases the CI by about 17 g/MJ.

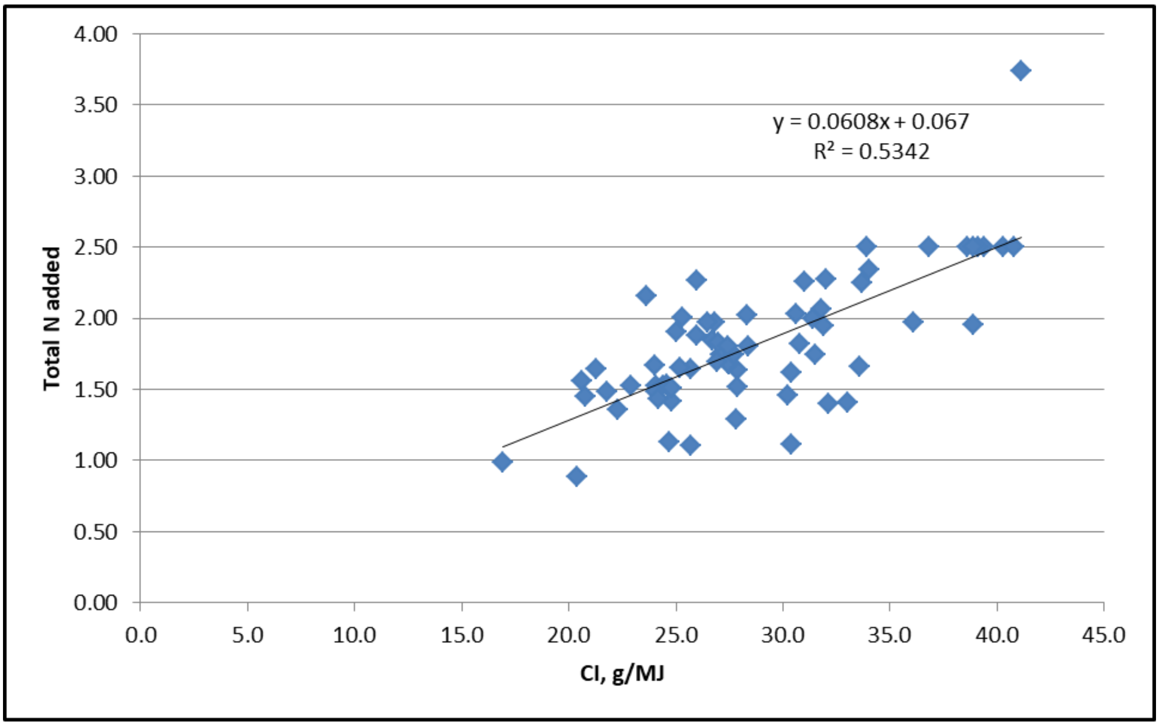

Figure 35 CI versus Nitrogen

The size of the plantation does not have a significant impact on the carbon intensity. This correlation is shown in Figure 36. While the trend line shows an increase in CI with smaller plantations, the R^2 is very low and not significant. The mills that used default values are excluded from this figure.

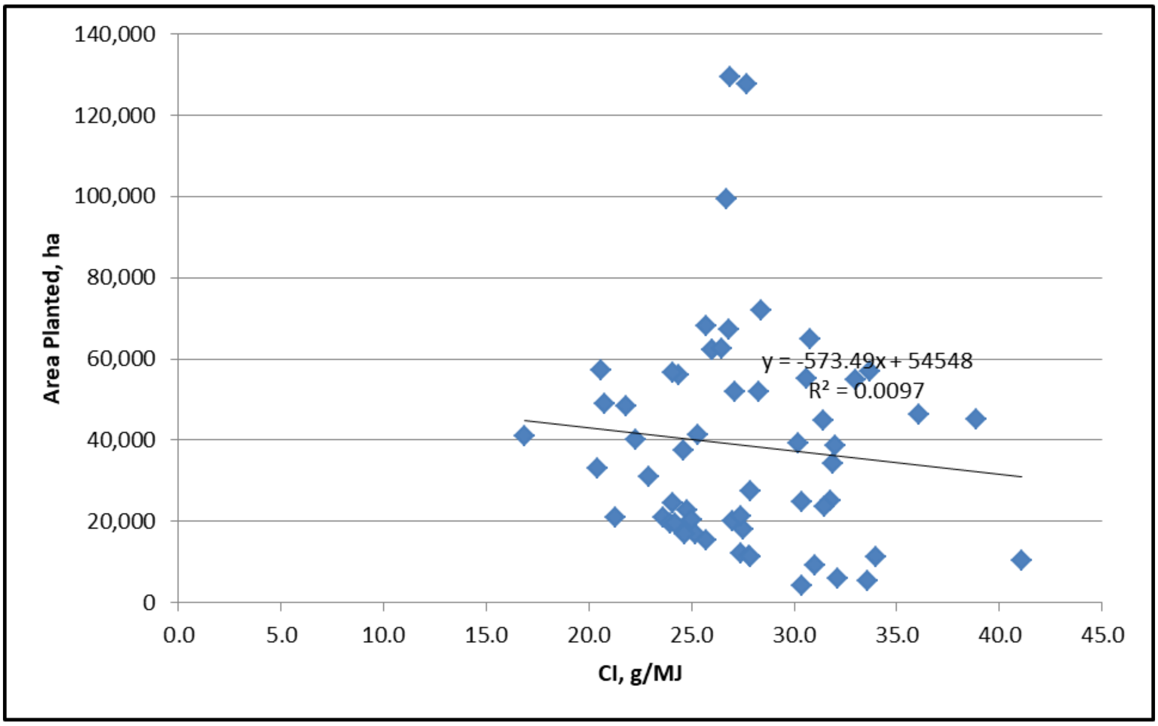

Figure 36 CI versus Planted Area

The correlation between the CI and the percentage of the area burned in shown in Figure 37. Again, while there is a trend to higher CI from plantations that have higher burn rates the correlation is very weak.

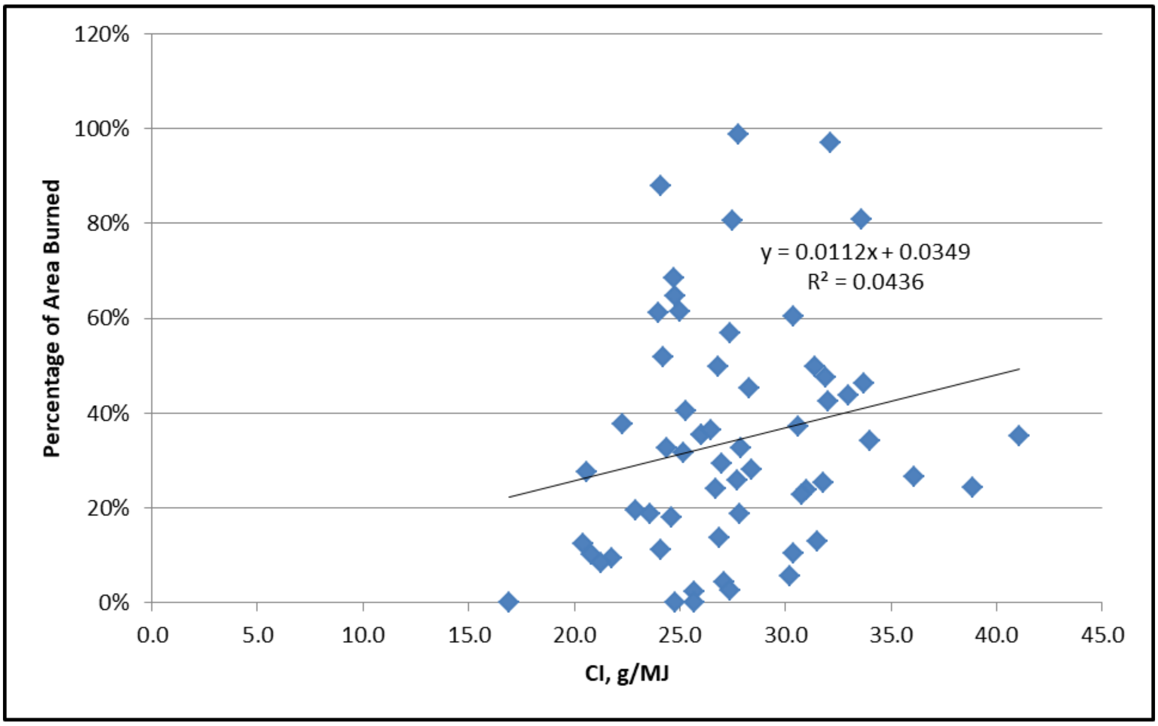

Figure 37 CI versus Percentage Area Burned

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Appendix 1 - RenovaBio Data Sheet

SUGARCANE PRODUCTION

Fase agrícola - Dados Consolidados

Informações gerais

Área total		ha			
Produção total colhida para moagem		t cana			
antidade comprada pela unidade produtora de biocombustível		t cana			
Teor de impurezas vegetais (base úmida)		kg/t cana	Umidade		
Teor de impurezas minerais		kg/t cana			
Palha recolhida (base seca)		t palha			

Área Queimada

Área queimada		ha

Corretivos

Calcário calcítico		kg/t cana
Calcário dolomítico		kg/t cana
Gesso		kg/t cana

Fertilizantes Sintéticos

Ureia		kg N/t cana
Fosfato monoamônico (MAP)		kg N/t cana
Fosfato monoamônico (MAP)		kg P_2O_5/t cana
Fosfato diamônico (DAP)		kg N/t cana
Fosfato diamônico (DAP)		kg P_2O_5/t cana
Nitrato de amônio		kg N/t cana
Solução de nitrato de amônio e ureia (UAN)		kg N/t cana
Amônia anidra		kg N/t cana
Sulfato de amônio		kg N/t cana
Nitrato de amônio e cálcio (CAN)		kg N/t cana
Superfosfato simples (SSP)		kg P_2O_5/t cana
Superfosfato triplo (TSP)		kg P_2O_5/t cana
Cloreto de potássio (KCl)		kg K_2O/t cana
Outros: especificar		kg N/t cana
Outros: especificar		kg P_2O_5/t cana
Outros: especificar		kg K_2O/t cana

Fertilizantes Orgânicos/Organominerais

Vinhaça		L/t cana	Concentração de N		g N/L
Torta de Filtro (base úmida)		kg/t cana	Concentração de N		g N/kg
Cinzas e fuligem (base úmida)		kg/t cana	Concentração de N		g N/kg
Outros: especificar		kg/t cana	Concentração de N		g N/kg
Outros: especificar		kg/t cana	Concentração de N		g N/kg

Combustíveis e eletricidade

Diesel - B8		L/t cana		
Diesel - B10		L/t cana		
Diesel - BX		L/t cana	Teor de biodiesel na mistura	
Diesel - B20		L/t cana		
Diesel - B30		L/t cana		
Biodiesel - B100		L/t cana		
Gasolina C		L/t cana		
Etanol hidratado		L/t cana		
Biometano de terceiros		Nm^3/t cana		
Biometano próprio		Nm^3/t cana		
Eletricidade da rede - mix médio		kWh/t cana		
Eletricidade - PCH		kWh/t cana		
Eletricidade - biomassa		kWh/t cana		
Eletricidade - eólica		kWh/t cana		
Eletricidade - solar		kWh/t cana		

ETHANOL PRODUCTION

Fase industrial - processamento do etanol					
Processamento e rendimentos					
Quantidade de cana processada		t cana			
Quantidade de palha processada (base seca)		t palha			
Rendimento Etanol Anidro		L/t cana			
Rendimento Etanol Hidratado		L/t cana			
Rendimento Açúcar		kg/t cana			
Rendimento Energia Elétrica Comercializada		kWh/t cana			
Rendimento Bagaço Comercializado (base úmida)		kg/t cana	Umidade		
Combustíveis e eletricidade					
Bagaço próprio					
Quantidade (base úmida)		kg/t cana			
Umidade					
Palha própria					
Quantidade (base úmida)		kg/t cana			
Umidade					
Bagaço de terceiros					
Quantidade (base úmida)		kg/t cana			
Umidade					
Distância de transporte		km			
Palha de terceiros					
Quantidade (base úmida)		kg/t cana			
Umidade					
Distância de transporte		km			
Cavaco de madeira					
Quantidade (base úmida)		kg/t cana			
Umidade					
Distância de transporte		km			
Lenha					
Quantidade (base úmida)		kg/t cana			
Umidade					
Distância de transporte		km			
Resíduos florestais					
Quantidade (base úmida)		kg/t cana			
Umidade					
Distância de transporte		km			
Óleo combustível		L/t cana			
Etanol hidratado próprio		L/t cana			
Etanol anidro próprio		L/t cana			
Biogás próprio		Nm^3/t cana	PCI do biogás		MJ/Nm^3
Biogás de terceiros		Nm^3/t cana	PCI do biogás		MJ/Nm^3
Eletricidade da rede - mix médio		kWh/t cana			
Eletricidade - PCH		kWh/t cana			
Eletricidade - biomassa		kWh/t cana			
Eletricidade - eólica		kWh/t cana			
Eletricidade - solar		kWh/t cana			

Appendix 2 – RenovaBio Emission Factors

Most of the individual mills submissions were done using version 6 of the RenovaBio calculator. There was little additional information that could be extracted because there were hidden sheets in the calculator. Version 7 of the calculator has hidden sheets but they are not locked and can be made visible. Table 8 presents the information that was used to calculate the nitrogen additions from the crop residues.

Table 8 RenovaBio Data for N_2O Calculations

	Values
Dry mass fraction sugarcane	0.3
Quantity of straw (dry) t/t cane	0.14
N content in aerial part residues (kgN/t straw)	4.77
Ratio between roots and shoot	0.20
Root N content (kgN/kg root)	5.14
Root quantity	0.088
Kg N in residue/t cane	1.12

The emission factors that are used in the RenovaBio calculator are presented in Table 9. All of these emission factors except the last two in the table were from ecoinvent 3.1. The last two are from CTBE.

Table 9 RenovaBio Emission Factors

	Values, g CO_2eq/kg
Lime {RoW}| production, milled, loose	36.8
Gypsum, mineral {RoW}| gypsum quarry operation	2.8
Urea, as N {RoW}| production	3,211.20
Nitrogen fertilizer, as N {RER}| monoammonium phosphate production	3,262.50
Phosphate fertilizer, as P2O5 {RER}| monoammonium phosphate production	1,662.30
Nitrogen fertilizer, as N {RER}| diammonium phosphate production	3,369.90
Phosphate fertilizer, as P2O5 {RoW}| diammonium phosphate production	1,446.50
Ammonium nitrate, as N {RoW}| ammonium nitrate production	8,226.60
Nitrogen fertilizer, as N {RoW}| urea ammonium nitrate production	5,697.00
Ammonia, liquid {RoW}| ammonia production, steam reforming, liquid	1,976.10
Ammonium sulfate, as N {RoW}| ammonium sulfate production	1,803.30
Nitrogen fertilizer, as N {RoW}| calcium ammonium nitrate production	8,313.20
Ammonium nitrate, as N {RoW}| calcium nitrate production	2,780.40
Phosphate fertilizer, as P2O5 {RoW}| single superphosphate production	2,367.70
Phosphate fertilizer, as P2O5 {RoW}| triple superphosphate production	1,876.40
Potassium chloride, as K2O {RoW}| potassium chloride production	455.2
Urea, as N {RoW}| production	3,211.20
Phosphate fertilizer, as P2O5 {RoW}| single superphosphate production	2,367.70
Potassium chloride, as K2O {RoW}| potassium chloride production	455.2
Glyphosate {RoW}| production	11,505.70
2,4-dichlorophenol {RoW}| production	5,081.70
Pesticide, unspecified {RoW}| production	10,742.50
Quicklime, milled, loose {RoW}| production	961.7
Citric acid {RoW}| production	27,470.30
Hydrochloric acid, without water, in 30% solution state {RoW}	1,675.70
Hydrochloric acid, 30% in H2O, at plant/BR U	780.3
Sulfuric acid {RoW}| production	109.4
Phosphoric acid, industrial grade, without water, in 85% solution state {RER}	1,512.90
Lubricating oil {RER}| production	1,131.40
Sodium hydroxide, 50% in H2O, market mix, at plant/CTBE BR U	512.5
Yeast paste, from whey, at fermentation/CH U	1,049.70
Ammonia, liquid, at plant, production mix/CTBE BR	3,059.30

The electricity emission factors that are included in RenovaBio are shown in Table 10. They are from ecoinvent version 3.1.

Table 10 Electricity Emission Factors

	Values, g CO_2eq/kWh
Electricity, high voltage, production BR, at grid/BR U	145.8
Electricity, high voltage {RoW}| electricity production, hydro, run-of-river	4.3
Electricity, high voltage {BR}| cane sugar production with ethanol by-product	79.3
Electricity, high voltage {BR}| electricity production, wind, 1-3MW turbine, onshore	147.4
Electricity, low voltage {RoW}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si	80.7
Electricity, medium voltage, production BR, at grid/BR U	149.7

The emission factors for fuels that are used are shown in Table 11. The emission factors are from ecoinvent version 3.1.

Table 11 Emission Factors for Fuels

	Unit	Values, g CO_2eq/unit
Natural gas, high pressure {RoW}	Nm^3	120.7
Diesel, low-sulfur {RoW}	kg	556.1
Liquefied petroleum gas {RoW}	kg	0.632
Gasoline, low-sulfur {RoW}	kg	0.761
Wood chips, wet, measured as dry mass {RoW}	kg	0.032
Heat, district or industrial, other than natural gas {RoW}	MJ	94

The transport emissions factors are shown in Table 12. The values are all from ecoinvent version 3.1.

Table 12 Transport Emission Factors

	Values, g CO_2eq/tkm
Transport, lorry 7.5-16t, EURO3/RER U	236.5
Transport, freight, lorry 16-32 metric ton, EURO3 {RoW}	183.8
Transport, lorry >32t, EURO3/RER U	120.1
Transport, freight, sea, transoceanic tanker {GLO}| processing	6.1
Transport, freight, inland waterways, barge tanker {RoW}| processing	48.6

IEA Bioenergy

Technology Collaboration Programme