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LCA of the South African sugar industry

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A life cycle assessment of sugar produced in South Africa evaluates the environmental impacts and energy consumption of the different life cycle phases of sugar production. The system studied includes sugar cane farming, fertiliser and herbicide manufacture, cane burning, sugar cane transportation and sugar manufacture. Inventory and impact assessment results show that non-renewable energy consumption is 5350 MJ per tonne of raw sugar produced and 40% of this is from fertiliser and herbicide manufacture. Reduction in the use or impact of fertiliser for cane farming could bring considerable savings in terms of fossil energy consumption and a reduction in greenhouse gas emissions.

Keywords: sugar; energy; farming; greenhouse gas; environmental

1. Introduction

South Africa is one of the world's leading producers of high quality sugar, producing approximately 2.5 million tonnes per annum. The South African sugar industry makes a significant contribution to the South African national economy, generating direct income of approximately 6 billion South African Rand (R) per year (US$700 million or €500 million) (SASA 2008). The industry employs approximately 85,000 people in cane production and processing, and also indirectly provides jobs in numerous support industries such as fertiliser, chemical, transport and food industries (SASA 2008). The sugar cane produced from farming areas is supplied to 14 mills in South Africa for processing into sugar. Most of the mills are located in the cane growing areas of KwaZulu Natal except for two mills in Mpumalanga. Table 1 shows sugar production in South Africa from 1994 to 2008.

The industry uses bagasse, the fibrous waste material remaining after the juice has been extracted from the sugar cane, to provide process heat for the boilers. According to Tongaat Hulett Ltd., every 100 tonnes of sugar cane harvested and milled produces 11.8 tonnes of sugar and 28–30 tonnes of bagasse with a moisture content of approximately 50% (Tongaat Hulett 2009). The sugar cane mills

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Table 1. Sugar production in South Africa.

Season	Cane crushed (M tonnes)	Sugar produced (M tonnes)	
		Domestic consumption	Export
1994/1995	14.2	1.2	0.3
1995/1996	15.2	1.2	0.3
1996/1997	19.0	1.1	0.9
1997/1998	20.1	1.2	1.0
1998/1999	20.8	1.2	1.2
1999/2000	19.2	1.1	1.2
2000/2001	21.7	1.1	1.4
2001/2002	21.7	1.1	1.1
2002/2003	20.9	1.2	1.3
2003/2004	18.5	1.2	1.0
2004/2005	17.3	1.1	0.9
2005/2006	19.1	1.1	1.1
2006/2007	18.4	1.2	0.8
2007/2008	17.9	1.3	0.8

Source: SASA (2008).

co-generate electricity from bagasse mainly for their own consumption, with a small amount exported to the small communities around the mills.

2. Methodology

The research methodology applied in this study is based on ISO (International Organisation for Standardisation) Standard 14044, in which a Life Cycle Assessment (LCA) is divided into four phases: goal and scope definition, inventory analysis, impact assessment, and interpretation. This study aims to:

- Compare the environmental performance of the sugar industry in South Africa with other sugar producing countries.
- Quantify the resource and energy consumption for the industry across the whole life cycle.
- Identify opportunities for improving the environmental performance of the system.
- Develop an environmental model for use in further LCA studies.

The functional unit for this study is 1 tonne of raw sugar produced using current South African technology. This technology produces about 35kWh of electricity from one tonne of cane crushed, essentially all of which is used in-house (Department of Minerals and Energy, Republic of South Africa 2004a, 2004b).

2.1. System boundaries

The system boundary consists of the growing and harvesting of sugar cane in South Africa all the way to the production of sugar and co-generation of electricity from bagasse at the sugar mills. The system boundary ends at the production of raw sugar at the factory gate. The following subsystems are considered:

(1) *Cane cultivation and harvesting*. Most of the cane is produced in KwaZulu Natal. Only 20% of the cane is under irrigation and most of the cane areas rely on rainfall (Department of Minerals and Energy, Republic of South Africa 2004b). Fertilisers and herbicides are applied to the sugar cane and the quantities vary from one area to the other depending on soil type and rainfall amounts. Average fertiliser application rates were adopted for the study.
(2) *Cane transportation to sugar mills* is by both road and rail. Approximately 94% of the cane is transported by trucks and the remaining 6% by rail.
(3) *Fertiliser and herbicide manufacturing*. The energy and other impacts of fertiliser and herbicide manufacture are included.
(4) *Sugar milling and electricity generation*. All 14 sugar mills in South Africa are considered with an average cane throughput at each mill of 300 t/h (tonnes/hour) or 1.5 million tonnes of cane per annum over an eight to nine month crushing season during which time the mills operate continuously (Department of Minerals and Energy, Republic of South Africa 2004b). At this throughput the boiler capacity was taken as over 160 t/h of steam at a pressure of 3000 kPa (Kilopascal) (a) and a temperature of 400°C. The steam is expanded through back pressure steam turbine prime movers and turbo alternators to 200 kPa (Department of Minerals and Energy, Republic of South Africa 2004b).

The following subsystems are excluded from the study:

- The production, maintenance and decommissioning of capital goods such as buildings and machinery.
- The production of cuttings used in the establishment of the sugar cane plantations.
- The distribution and transmission of generated electricity.
- The road and rail transportation infrastructure.
- The transportation of sugar to consumers and storage.

2.2. Data collection for the inventory

Data for the processes were obtained from the sugar plantations in Kwa Zulu Natal in South Africa. The data relating to the manufacture of fertilisers and herbicides were obtained from literature. Efforts were made to model the system in such a way that it represents as far as possible current agricultural practices and manufacturing technologies used in South Africa. The sugar mills, Sugar Milling Research Institute (SMRI) and the South African Sugar Association (SASA) also contributed to the data. Part of the information was obtained from documents from the Department of Minerals and Energy in South Africa. Data were also obtained from the Eco-invent database in SimaPro and were compared to other assessments carried out in other countries and were checked using mass and energy balances. Data were also modified in SimaPro to be more relevant to the South African industry; for example, electricity from South Africa was modelled in SIMAPRO in order to avoid use of electricity data from other countries. In Figure 1 the sub-systems that are included in the study are shown inside the border line.

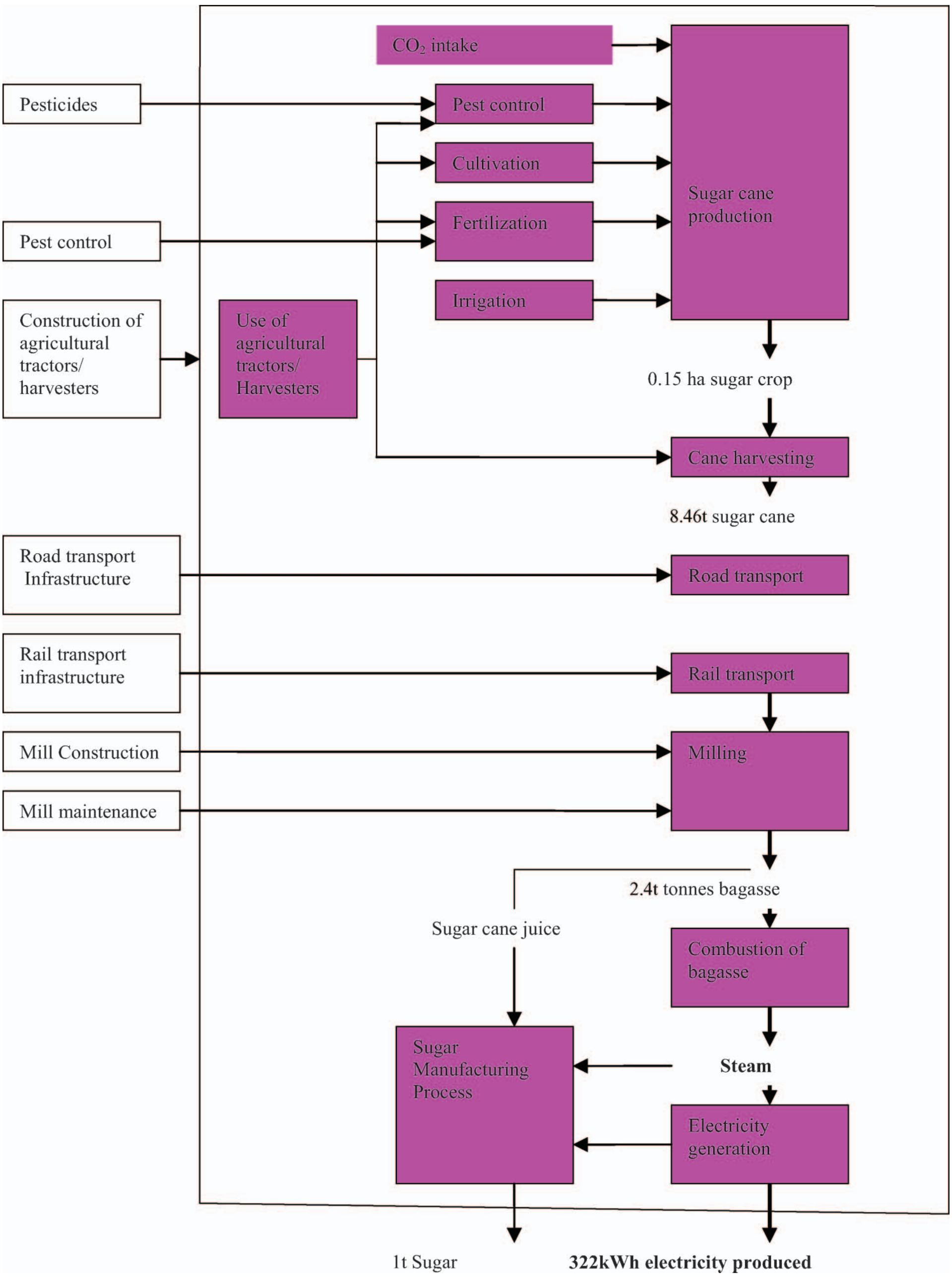

Figure 1. System boundary. The subsystems considered are shown inside the border line.

2.3. *Impact assessment*

The impact assessment stage involves the interpretation of the life cycle inventory to assess the impact of the system on human health and the environment. The impact assessments were done using SimaPro Software. Eco-indicator 99 impact assessment methodology was used rather than eco-indicator 95 or CML 2000 because eco-indicator 99 includes land use, particulate matter and fossil fuel depletion, all of which are relevant to the system studied here (Pre, Product Ecology Consultants 2006).

3. Life cycle inventory

Table 2 shows data and assumptions used for the lifecycle inventory. Table 3 summarises resource inputs for sugar production. Tables 4 and 5 summarise emissions to soil and air and water, respectively. Table 6 summarises by-products of sugar production, and Table 7 summarises external transport data.

3.1. Emissions from cane burning

Emissions for sugar cane burning were calculated assuming a yield of 280 kg of tops and dry leaves at 50% moisture per metric tonne of cane harvested (Wang *et al.* 2008).

3.2. Fossil energy consumption

Energy consumption was compiled for the following stages: cane farming, transportation, cane burning, fertiliser and herbicide manufacture and sugar manufacture per tonne of sugar produced. The fossil fuel consumed in the whole process is a summation of the different quantities of fossil fuels consumed during farming, transportation and sugar manufacture. Energy required for producing farming machinery was excluded from the study; agricultural inputs are considered separately below, as is cane transportation. Therefore, assuming an average of 8.46 tonnes of cane used to produce 1 tonne of sugar, the total fossil energy required for farming purposes is 372 MJ/t of sugar produced.

Fossil fuel energy for transportation was considered, taking into account both road and rail transportation. It is reported that 6% of the cane is transported using rail and 94% using road trucks. The energy consumption for rail in South Africa was assumed to be 0.68 MJ/tkm (City of Cape Town 2005). The fuel consumption for a truck was considered to be 0.075l per tkm, and the energy content for diesel was taken as 37 MJ/litre (Ramjeawon 2004). The total transportation fossil energy required to produce a tonne of raw sugar was calculated as 1893 MJ.

During sugar manufacture fossil fuel energy use is a result of coal used to start up boilers and to supplement bagasse supplies during the off-season. The coal consumed is multiplied by the net calorific value (NCV) of coal. Sugar industry data show that approximately 70.8 kg of coal is required to produce a tonne of sugar. The NCV of South African coal is 19.739 MJ/kg (Thomas *et al.* 2000). Total energy use from coal was calculated as 1397 MJ/t of raw sugar produced.

Fossil fuel energy for fertiliser and herbicide use was calculated using the energy requirements to produce fertilisers and herbicides and application rates used in South Africa. The application rate of fertiliser is 120 kg N, 30 kg P2O5 and 125 kg K2O per hectare. The amount of land required to produce 1 tonne of sugar is 0.15 ha (Department of Minerals and Energy, Republic of South Africa 2004b). The total amount of energy consumed in fertiliser production was then found to be 1113 MJ per tonne of raw sugar that is produced. Including

Table 2. Assumptions and data.

	Value/assumptions	References
1 Sugar cane agriculture		
Cultivation area	400,000 ha	Dept Minerals and Energy, SA 2004b
Average cane harvest per hectare	60t (6 t of sugar)	Dept Minerals and Energy, SA 2004b
Irrigation water requirements/ha	17,000m^3	Ramjeawon 2004
Electricity consumption/ha for irrigation	216k Wh	Ramjeawon 2004
N_2O emissions from soil	1.25% of nitrogen input	IPCC 2006a
NOx emissions from soil	0.5% of nitrogen input	Ramjeawon 2004
Fertiliser application/ha	120 kg N, 30 kg P_2O_5 and 125 kg K_2O	[Sugar industry data]
Herbicides use	26.9 g/MT of sugar cane	Wang *et al*. 2008
Herbicides loss in water bodies	0.2%	Wang *et al*. 2008
Nitrogen loss in water bodies	10%	Ramjeawon 2004
Phosphorus loss in surface runoff/ ha	1kg	Ramjeawon 2004
Pesticide use	2.21g/MT of sugar cane	Wang *et al*. 2008
2 Cane burning		
Cane area burnt before harvesting-	90% - 360 000 ha 280 kg of leaves and tops burnt/hectare	Dept Minerals and Energy, SA 2004b
3 Inorganic fertiliser and herbicides		
Energy required for herbicide production per kg	120 MJ	Ramjeawon 2008
Fuel input to produce herbicide/kg	15% diesel, 70% coal and 15% electricity	Ramjeawon 2004
Energy required to produce N fertiliser/kg	48 MJ	Wang 2009
Energy required to produce P_2O_5/kg	14 MJ	Wang 2009
Energy required to produce K_2O/kg	8 MJ	Wang 2009
Fuel input in production of fertilisers	natural gas, electricity, coal, diesel	
4 Cane transportation		
Transportation by road average distance	90km	[Sugar industry data]
Transportation by rail average distance	50km	[Sugar industry data]
Diesel consumption litres/t km	0.075l diesel 37MJ/litre	City of Cape Town 2005
Fertilisers and herbicides transport distance	60 km	
5 Sugar processing and electricity generation		
Sugar produced/ha under cultivation	6.0t	[Sugar industry data]
Bagasse produced	27.8% of cane	[Sugar industry data]
Molasses produced/ha	4.1% of cane	[Sugar industry data]
Filter cake produced/ha (used as fertiliser)	6.8% of cane	[Sugar industry data]
Electricity exported to the grid	0.00	[Sugar industry data]
Steam consumed/t of cane	520kg	[Sugar industry data]
Electricity consumption/t of cane	35kWh	[Sugar industry data]
Coal consumption/t of cane	8.4kg	[Sugar industry data]
Water used for cane processing/t cane	0.6m^3	[Sugar industry data]
Pollutant loadings of COD/t of cane	3320	[Sugar industry data]
Pollutant loadings of BOD5/t of cane	1590	

Table 3. Resource inputs for production of 1 tonne of raw sugar.

Resource	Quantity
Sugar cane	846 tonnes
Raw water	17000 m^3
Land	0.15 ha
Coal	71 kg

Table 4. Emissions to soil from production of 1 tonne of raw sugar.

Emission type	Quantities (kg/tonne sugar)
Ashes and slags	368
Hazardous waste	0.03

Table 5. Emissions to air and water.

	kg per tonne of sugar
Air emissions	
CH_4	7.5
CO_2 (fossil)	196
N_2O	0.5
SO_x (as SO_2)	2.18
NOx (as NO_2)	7.5
NMVOC[2]	0.07
Suspended particulate matter	0.85
Water emissions	
BOD_7	6.6
COD	19
NO_3^-	12
PO_4^{3-}, tot	0.15
Suspended solids	0.05
Fe	0.00126

Table 6. By-products (annual mean tonnes per tonne sugar).

	Quantity
Filter cake	0.56 t
Molasses	0.38 t

herbicides, the total fossil energy required for agricultural inputs is 1140 MJ/t and the total fossil fuel use is 5350 MJ per tonne of sugar.

3.3. Renewable energy use

This was calculated using the net calorific values (NCV) of bagasse of 7.670 MJ/kg. 18,400 MJ of renewable energy from bagasse are required to produce a tonne of sugar. The total energy consumption for the system, both renewable and non-renewable, is about 23,800 MJ/ tonne of sugar produced.

Table 7. Data on external transport.

Transport Type	Average distance, km	Additional data
Truck	90	50% empty returns
Rail	50	Diesel train

3.4. Emissions into the air

Emissions into the air for a tonne of sugar produced were calculated by summing up the emissions at each stage of the life cycle for all the parameters that were under study. Emissions were again compiled for all the stages under consideration: cane farming, cane burning, cane transportation, fertiliser and herbicide manufacture and sugar manufacture. For nitrous oxide (N_2O) the emissions were summed up for emissions from soil, cane burning and bagasse combustion. The N_2O emissions factor from the soil was taken to be 1.25% of the applied nitrogen (Ramjeawon 2008). N_2O emissions from cane burning and bagasse combustion were calculated using assumptions from Wang *et al*. (2008). The total N_2O emissions into the air for the whole sugar life cycle were estimated to be 0.47 kg per tonne of sugar produced.

Carbon dioxide (CO_2) (fossil) emissions into the air were also summed up for all the stages that have a significant contribution. The CO_2 emissions from fossil fuel combustion during farming operations, sugar cane transportation and combustion of coal during sugar manufacture were considered. The CO_2 emission from cane burning was excluded because it was assumed the sugar cane releases the CO_2 that it absorbed during photosynthesis. For farming and cane transportation the carbon dioxide produced was calculated using carbon content data obtained from the US Environmental Protection Agency (EPA) (USEPA 2005). Diesel carbon content per litre is 0.734 g (USEPA 2005). Calculations then show that the CO_2 emission per litre of diesel is 2.7 kg per litre of diesel burnt. This is true based on the assumption that 99% of the carbon is oxidised and only 1% remains un-oxidised for oil and oil products, giving an oxidation factor of 0.99 (USEPA 2005).

Total carbon dioxide emission from cane farming and transportation are 27 kg and 137 kg per tonne of raw sugar respectively. During sugar manufacture most of the carbon dioxide produced is from coal combustion for process steam and electricity. CO_2 (fossil) from coal was calculated using a carbon content of 80% because coal from South Africa is mainly anthracite. Combustion of 70.8 kg of coal, if it is 80% carbon (anthracite), will result in 108 kg of carbon dioxide for every tonne of raw sugar produced. Total fossil carbon dioxide over the whole life cycle is 383 kg/t of raw sugar produced.

Sulphur dioxide (SO_2) emissions in the sugar life cycle emanate from the cane farming, cane burning cane transportation and during the combustion of coal to produce steam for sugar processing. The SO_2 from cane farming was calculated considering the quantity of diesel consumed in relation to the diesel sulphur content. The sulphur content for diesel used in this study was 0.3% (de Vaal 2004). Calculations reveal that about 10.69 litres are required to produce a tonne of sugar and this in turn results in 0.06 kg of SO_2 emitted into the atmosphere. The emission factor used to calculate SO_2 emissions from cane burning was 0.4 per kg of dry leaves burnt (Wang *et al*. 2008).

SO_2 emissions from this stage are 0.95 kg. The SO_2 produced during sugar cane transportation was calculated taking into account the amount of diesel consumed during transportation of sugar cane to mills by road and rail, in this case 21.78 litres and 0.3% as the percentage of sulphur in the diesel. The result is 0.13 kg of SO_2 produced per tonne of sugar during cane transportation. Most of the SO_2 emissions for sugar manufacture are from coal with a sulphur content of 1.3% (Jeffrey 2005). With coal consumption for sugar manufacture at 70.8 kg per tonne of sugar produced the amount of sulphur from coal burning is 0.96 kg per tonne of sugar produced. The total SO_2 produced per functional unit is 3.23 kg.

Methane emissions were calculated using the following assumptions: 2.7 g produced per kg of cane and tops burned according to IPCC guidelines (IPCC 2006b). An average emission factor of 30g/1000 MJ of bagasse burnt was used for methane emissions from bagasse combustion (IPCC 2006c). CH_4 emissions from cane burning are 6.95 kg. Methane emissions from bagasse combustion are 0.6 kg. The total methane emissions for the whole life cycle per tonne of sugar produced are 7.55 kg.

Nitrogen oxides (NOx) emissions were also calculated for all the stages of sugar life cycle. NOx emissions from cane burning were calculated using an emission factor of 2.5g per kg of dry leaves and tops burned. The total NOx emissions amount to 7.51 kg.

4. Impact assessment

4.1. Global warming potential (GWP)

Most of the global warming potential results from the sugar plantation stage of the sugar life cycle were due to the emission of nitrous oxides released from the soil as well as the carbon dioxide emissions from fossil fuel consumption during fertiliser and herbicide manufacture (Figure 2). Fossil fuel combustion during farming activities also contributes significantly to this impact category. Sugar cane burning is also a significant contributor to this impact category. This is a result of methane emissions during cane burning. Transportation is also a significant contributor, and

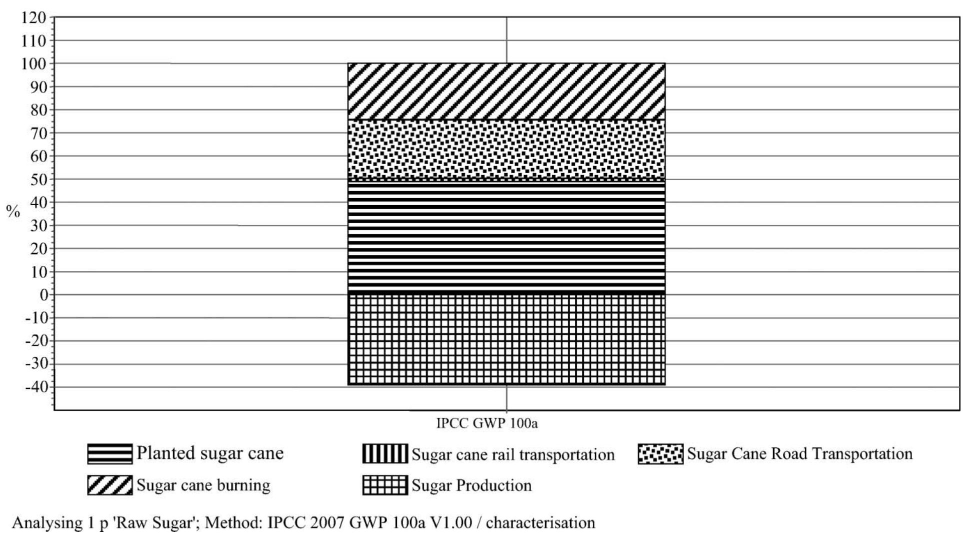

Figure 2. Greenhouse gas emissions (g CO_2 equivalent) based on 100-year GWP.

sugar manufacture has a negative contribution as a result of avoided greenhouse gas emissions when bagasse substitutes are used instead of coal during sugar manufacture.

When global warming potentials over 20 years are considered instead of 100 years, sugar cane burning contributes more to global warming than sugar cane farming.

4.2. Fossil fuel use

The contribution of the different stages to fossil consumption use over the whole life cycle of sugar is summarised in Figure 3.

Figure 3 shows road transportation is the highest contributor to fossil fuel use and it accounts for almost 50% of fossil energy due to fuel use. Planted sugar cane also has a significant contribution to fossil fuel use as a result of fuels used for farming activities and fossil fuel use during fertilizer and herbicide production. This stage accounts for close to 34% of the life cycle fossil fuel use. Rail transportation has a lesser contribution compared to road transportation because only about 6% of the sugar cane is transported by rail and the rest of it by road. Sugar manufacture makes use of renewable bagasse for boilers and therefore its contribution is negative because it uses more renewable energy than fossil energy.

4.3. Ozone depletion and acidification

Ozone depletion is mainly a result of sugar cane transportation, followed by sugar cane farming. This is a result of air emissions from these processes. Figure 3 shows that acidification and eutrophication are mainly a result of sulphur dioxide emissions during cane burning. Planted cane also contributes significantly to eutrophication as a result of nitrates from fertiliser application being washed into water sources. Road transportation also has a minor contribution to this impact category.

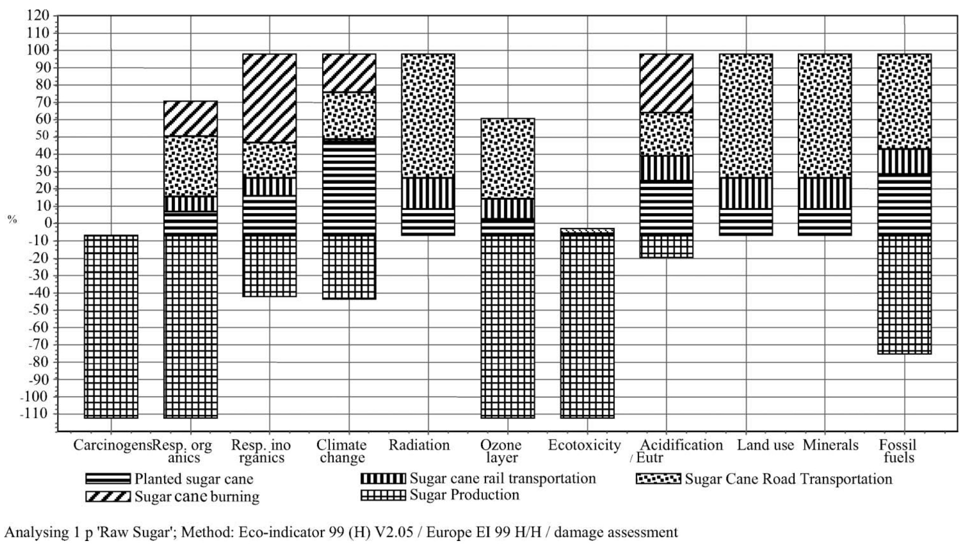

Figure 3. Results of characterisation and damage assessment.

4.4. Ecotoxicity

Road transportation has the most significant contribution to this impact category, as illustrated in Figure 3. However, the overall contribution of the whole life cycle to this impact category is minor.

4.5. Summary of impacts

Based on the inventory and impact assessment results, the following conclusions can be drawn concerning the contribution of the different processes to the life cycle of South African produced raw sugar.

- The greatest contributor to non-renewable fossil fuel consumption is road transportation. Therefore, optimisation of sugar cane delivery routes can yield significant savings in fossil energy use.
- Fertilizer and herbicide manufacture are also significant contributors to this impact category.
- Sugar manufacture has a negative contribution to this impact category because it consumes far much more renewable energy than fossil fuel.
- Sugar cane farming has the greatest contribution to global warming and climate change.
- Respiratory organics and respiratory inorganics are mainly from cane burning to allow for harvesting as a result of nitrous oxide emission from the soil and greenhouse gas emission from fossil fuel consumption during farming activities.
- Acidification and eutrophication are mainly a result of sugar cane burning.

5. Discussion and recommendations

5.1. Comparison of results with other LCAs

The results of the study show some similarities with other studies about the sugar industry in the African context. The study was also compared to other LCAs that were carried out in the sugar industry in South Africa, although these were on bio-ethanol and green electricity from sugar cane bagasse (Blottnitz and Curran 2007). Comparison of the results is feasible because the first stages of the system boundaries are the same up to the point that the sugar cane enters the sugar mill. This study shows that approximately 34% of the fossil energy consumption is a result of cane farming activities, compared to the 75% attributed to cane farming in Mauritius (Ramjeawon 2004). The total fossil energy consumption per tonne of cane for this study is 5350 MJ compared to 1995 MJ for Mauritius. In Mauritius, 0.12 ha of land is required to produce a tonne of cane compared to 0.15 ha for South Africa; this is mainly because only 20% of South African cane is irrigated and the rest is rain fed. In addition, most electricity and steam used in Mauritius is from more efficient use of renewable bagasse.

The two studies both show that the use of fertilisers and herbicides are the greatest contributors to global warming through the use of fossil fuels in their manufacture. A total of 74% of the contribution to global warming impact is a result of cane farming and harvesting activities compared to 80% in the Mauritian case study. In South Africa, the net energy gain, the ratio between electricity produced and the fossil fuel energy consumed in the system, is currently 4.2 as calculated in this study. This is far less than the net energy gain realised in Mauritius, which is about 13 (Ramjeawon 2008).

The LCA of ethanol in Brazil by Wang *et al.* (2008) shows that cane farming activities are responsible for 68% of the contribution to greenhouse gas emissions and this further emphasises the importance of the cane farming stage of the life cycle of sugar with regard to global warming and climate change. The elimination of cane burning activities can help to reduce greenhouse gas emissions at this stage. Macedo *et al.* (2008) have also found that Brazilian sugar cane production, harvesting and transportation consumes most of the energy from the lifecycle of ethanol produced from sugar. In Brazil, in 2002, 35% of the cane was harvested by machinery, whereas in South Africa it is entirely harvested manually.

It was difficult to compare the study with available South African case studies because most of them centred more on the LCA of sugar from the perspective of ethanol production and electricity co-generation as opposed to sugar production *per se* (Blottnitz and Curran 2007, Blottnitz *et al.* 2002).

5.2. Recommendations

The following section explores the potential to reduce the environmental burdens that result from the life cycle of sugar.

5.2.1. Fertiliser and herbicide use

The use of fertiliser and herbicides for sugar cane farming contribute to both global warming and fossil fuel consumption. Research should be directed at ways to improve the output of sugar cane with less impact from fertilisers.

5.2.2. Transportation systems

Transportation of sugar cane to the sugar mills is an integral part of the sugar industry supply chain. Inefficient transport processes can result in poor quality sugar if cut sugar cane is not delivered to the mills on time and at the right level of quality. It is therefore imperative to ensure the efficiency of this process whilst at the same time reducing its effect on the environment. Mostly road (94%) and to a lesser extent rail (6%) transportation systems are currently used to transport the sugar cane to the mills. Increased use of rail can reduce the environmental impacts but this is not feasible in most of the cane growing areas in South Africa because of the hilly terrain. However optimisation of the sugar cane road delivery system in the sugar industries can also result in cost savings and reduction in green house gas emissions.

5.2.3. Cane sugar burning

Open field burning of sugar cane, to allow for harvesting, is prevalent in South Africa. This study shows that this is one of the main sources of greenhouse gases. The industry should consider phasing out cane burning for two reasons: to reduce greenhouse gas emissions and to use the cane tops and waste – estimated to range from 10 to 20% of the amount of cane crushed (Samson *et al.* 2001) – as a fuel for the boilers to complement the use of bagasse. However, the South

African Sugar Research Institute (SASRI) prefers the trash to be left in the fields to return nutrients to the soil. The effect of using trash for energy generation would be a further reduction in net fossil energy use in sugar manufacturing substituted by renewable energy. There is a need to expedite the research and development of methods for harvesting the sugar cane leaves and the tops so that they can be used in boilers in the same way bagasse is used. The total amount of waste and tops produced can be expressed as a percentage of the total cane crushed.

5.2.4. *Reduction in water use and land use*

Only 20% of South African produced sugar cane is under irrigation and the rest of the cane is rain fed. The result has been higher yields in irrigated areas compared to areas that rely on rainfall. However, improved water management could increase water use efficiency. Improper water pricing structures discourage improvements in water use efficiency and these need to be examined. In irrigated areas the adoption of centre pivot irrigation systems can improve water efficiency (Marcovitch 2006).

5.2.5. *Improved co-generation of electric energy*

The co-generation of electricity from bagasse burning has been a beneficial characteristic of the sugar industry for a long time. However, some of the benefits of the process are not realised due to low process efficiencies. The power output in the South African industry per tonne of sugar cane crushed is approximately 30 kWh (Department of Minerals and Energy, Republic of South Africa 2004a). Generating efficiency for the sugar industry in South Africa could be increased up to 120 kWh/tonne using conventional steam plants running at higher pressures (Department of Minerals and Energy, Republic of South Africa 2004a). The result would be a further reduction in net energy use for sugar manufacture, thereby reducing carbon dioxide emissions and also reducing use of fossil fuel. This presents the industry with an opportunity to produce more electricity than they consume, thereby exporting the excess electricity to the grid.

5.2.6. *Adoption of energy management practices*

Efficient energy management systems can reduce energy consumption and reduce impacts on climate change. Traditional sugar factory design has focused on achieving a fuel balance that minimises the purchase of supplementary coal and avoids the generation of excess bagasse (Clay 2005). Potential improvements could include the use of lower grade vapours for heating purposes, an improvement in steam conditions, modifications of crystallisation pans, improved juice extraction methods, improved boiler efficiency and reducing the moisture content of bagasse.

6. Conclusion

The LCA study showed that sugar cane farming has the greatest contribution to global warming and climate change (see Figure 2). Fertiliser and herbicide manufacture has the highest contribution towards fossil energy depletion. The study also established that efficiency of energy generation at the sugar mills needs to be improved. Reduction in fertiliser use and the phasing out of cane burning can help reduce the industry's contribution towards global warming by reducing the amount of greenhouse gas produced. The South African Sugar Industry consumes more fossil energy compared to the amount consumed in Mauritius and Brazil, based on the studies that were used to make the comparisons. The findings and the recommendations of this study suggests that the sugar industry can significantly improve the environmental performance of its operations.

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