Carbon and water footprint assessment of the Mauritian sugar cane sector

- revised version -

Title	Carbon and water footprint assessment of the Mauritian sugar cane sector: revised version
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Date	Previous version: July 2020 Revised version: February 2021
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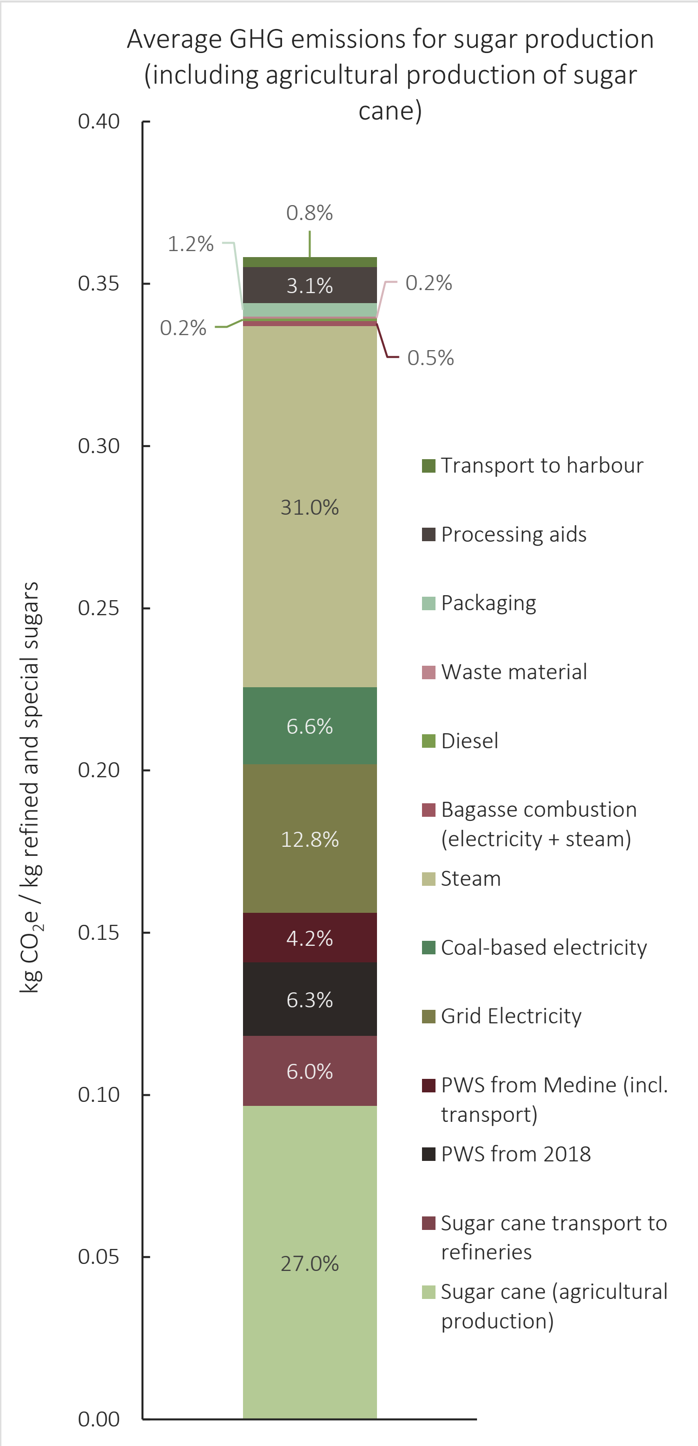
Note about the revised version:

The previous version of this report partially contained preliminary results for the agricultural stage of the carbon footprint of cane sugar. This led to minor discrepancies in the final results as displayed in the previous version of this report from the results actually calculated. The authors are indebted to the attentive reader who made us aware of this mistake, which we corrected in this revised version.

Content

1 Summary

This study assesses the product carbon and water footprint (WF) of Fairtrade sugar cane production and cane sugar products from Mauritius for the year 2019. The scope comprises greenhouse gas (GHG) emissions associated with the agricultural production of sugar cane, transport to refineries, local processing, and transport to the harbor. As an additional step, emissions caused by ocean transport to Europe were calculated. The WF was performed on an agricultural and processing level.



The cane sugar product carbon footprint amounts to 0.36 kg CO_2e per kg of both refined and special sugars delivered to Port Louis, Mauritius. Of the total emissions, 27.0% can be attributed to sugar cane cultivation, 6.0% to the transport from the farms to the refineries, 55.6% to processing in the refineries, and 0.8% to the transport from the refineries to the harbor, respectively. The remaining 10.6% are embodied GHG emissions of plantation white sugar from 2018 and from Medine refinery.

In terms of agricultural production, soil-build up and erosion prevention constitute the greatest opportunities for improving the overall product impact while generating valuable co-benefits.

Processing contributes the largest share of emissions, mainly due to the substantial quantity of steam consumed. However, associated with the processing stage is the generation of renewable electricity from sugar cane derived waste products, displacing national grid electricity and thus emissions of -0.53 kg CO_2e per kg sugar. The large positive impact of renewable electricity generation thus exceeds the negative climate impact of the entire cane sugar production process by 0.17 kg CO_2e per kg sugar from cradle to national harbour. Beyond that, efforts are under way to advance the circular production process, which should further reduce emissions. Ocean shipping to Europe would add another 0.24 kg CO_2e per kg sugar.

On average, 6.8 liters of surface and groundwater are used in agricultural production for 1 kg of sugar cane, with purely rain fed farms being considered as zero water usage production systems. Due to its overall low reliance on these sources, the blue WF of Mauritian Fairtrade sugar cane compares well globally. The water consumption average of irrigated farms is 21.4 liters/kg.
When related to processed sugar, water consumption attributable to the cultivation stage amounts to 67.0 liters per kg sugar, or 53.3 litres per kg sugar when accounting for the wastewater of the refineries used for irrigation of sugar cane. The average water consumption of the two sugar refineries assessed results in a blue water footprint of the processing stage of 9.8 liters per kg processed sugar. Combined, these two stages generate a blue water footprint of 76.8 liters per kg sugar, or 63.1 litres corrected for irrigation with wastewater.

2 General information

2.1 Introduction

Fairtrade International is the international non-profit, multi-stakeholder organization behind the FAIRTRADE Brand. Fairtrade currently works with over 1,240 producer groups across 75 countries, reaching some 1.66 million smallholder farmers and plantation workers.
As part of the Fairtrade Sourcing Ingredient program, the Fairtrade sugar cane sector in Mauritius (amongst others) and Fairtrade certified SPOs (small producer organizations) in Mauritius (>30) are beneficiaries of additional support in areas that increase their sustainability. Partners in Mauritius showed an interest that a study measuring the carbon and water footprint of the sector is carried out, that should not only measure the footprint but also propose mitigation and adaption strategies. Thereafter, any Fairtrade & non Fairtrade income could be strategically invested for adaption and mitigation measures.
This footprint study was carried out by Soil & More Impacts B.V. (hereafter referred to as “SMI”) with the support of members of the Mauritius Fairtrade Cooperative Federation.

2.2 Sector Profile

Sugarcane is presently cultivated on about 50,000 hectares, representing 75% of the arable land in Mauritius. On average, 325,000 tonnes sugar is produced annually with most being exported to the European Union. Sugar production remains an important contributor to the country's economy with sugar exports representing a little less than 20% of foreign exchange earnings and 1% of the country’s Gross Domestic Product (GDP). Milling operations have been progressively centralised, as a result of which only 3 mills remain in activity now. Mauritius contributes to 0.2 % to the world’s total sugar production. With the abolishment of the sugar beet production quota in the EU in 2017, market access into the EU and a drop of 20% in sugar prices has brought revenue for all sugar suppliers, whether beet or cane producers, lower than the costs of production[1].

Still, the agricultural sector, and its sugarcane cluster in particular, is forecasted to remain a source of wealth for the Mauritian economy, one of the country’s development pillars, and plays a vital multifunctional role in the socio-economic fabric of Mauritius. Structural reforms and improvement of resilience towards the impact of climate change are needed. The Fairtrade premium helps Mauritius sugar farmers to work in a profitable way. Currently, 5,254.717 ha of Mauritian sugar cane surface is Fairtrade certified.

2.3 Goals of the assessment and definitions

This study aims to calculate the CO_2e (carbon dioxide equivalent) and Water footprint of cane sugar from Mauritius from the agricultural and from the processing perspective. Focus is on Fairtrade Certified farms, but some non-certified farms are also included. The study shows the biggest emission sources and sinks and give recommendations for improvement.

The term “carbon footprint” stands for the total sum of all greenhouse gas emissions caused by a product’s life cycle. The system boundaries of the footprint are defined in section 2.2.
The carbon footprint serves to identify the environmental performance of a specific product or facility as to greenhouse gas emissions, thus assessing its impact on climate change.
Greenhouse gases (GHGs) absorb and emit radiation in the thermal infrared range of the electromagnetic spectrum and thus trap heat in the Earth’s atmosphere. Their resulting global warming potential is expressed by a coefficient specific to each GHG determined by the Intergovernmental Panel on Climate Change (IPCC). This study includes different greenhouse gases that are emitted during different stages of a product’s life cycle: carbon dioxide (CO_2),

methane (CH_4), and nitrous oxide (N_2O), CFCs and HCFCs. The Global Warming Potential (GWP) of methane and nitrous oxide is higher than the one of carbon dioxide, meaning that they are stronger greenhouse gases. In the following footprint, all identified greenhouse gases are converted into CO_2e (Carbon dioxide equivalents) by multiplying them with the GWP value.

Type of gas	Chemical formula	GWP 100
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298

Greenhouse gasses included in this study with their GWP value.

The term "water footprint" as defined by the Water Footprint Network measures the amount of water used to produce a goods or service. It can be measured in cubic metres per tonne of production, per hectare of cropland, per unit of currency and in other functional units. The water footprint helps us understand for what purposes our limited freshwater resources are being consumed and polluted. The impact it has depends on where the water is taken from and when. If it comes from a place where water is already scarce, the consequences can be significant and require action. The water footprint has three components: green, blue and grey. Together, these components provide a comprehensive picture of water use by delineating the source of water consumed, either as rainfall/soil moisture or surface/groundwater, and the volume of fresh water required for assimilation of pollutants.

2.3.1.1 The three water footprints:

2.3.1.1.1 Green water footprint is the amount of rainwater required (evaporated or used directly) to produce a unit. It is particularly relevant for agricultural, horticultural and forestry products.

2.3.1.1.2 Blue water footprint is the amount of surface water and groundwater required (evaporated or used directly) to produce a product. Irrigated agriculture, industry and domestic water use can each have a blue water footprint.

2.3.1.1.3 Grey water footprint is the amount of fresh water required to assimilate pollutants to meet specific water quality standards. The grey water footprint considers point-source pollution discharged to a freshwater resource directly through a pipe or indirectly through runoff or leaching from the soil, impervious surfaces, or other diffuse sources. The most critical pollutant sets the benchmark for the rest.

Source: Components of agricultural water footprint: green, blue and grey (from SAB Miller and WWF, 2009) from https://waterfootprint.org/en/water-footprint/what-is-water-footprint/

2.4 Functional Unit

For this carbon and water footprint assessment, the functional unit was identified to be **1 kg final product. i.e. refined and special sugars**, from cradle to harbour.
Therefore, all greenhouse gas emissions and water footprint caused by the primary production stage, the processing stage as well as transportation stage are broken down to the quantified unit of 1 kg final product.

3 Methodology

3.1 General methodology

The assessment has been done in line with the requirements of the GHG Protocol[22] developed by the World Resource Institute and the World Business Council for Sustainable Development. The calculation models and tools used for this assessment have been developed by SMI or have been provided by reliable service providers such as the Sustainable Food Lab respectively the Cool Farm Institute, using the Cool Farm Tool (https://coolfarmtool.org/) to assess the farming level emissions and Defra emission factors (www.gov.uk/government/collections/government-conversion-factors-for-company-reporting) to model the processing and transport emissions. For the water footprint, the model CropWat 8.0 and ClimWat 2.0 database was used (based on FAO 56 standard)[3] and the guidelines of the Global Water Footprint Network were followed[4].

The required primary data was collected by local Fairtrade representatives during on-site visits in November 2019. The data was uploaded to SMI's database and evaluated using our own models based on above-mentioned tools. Additionally, two processing mills were remotely interviewed by Soil & More Impacts and the data was manually evaluated. For the transport, generic distance and vehicle data was used.

3.2 System boundary and scopes

The term boundary specifies which processes are part of the assessment and are therefore accounted for in the carbon and water footprint. Once the system boundary has been defined, the greenhouse gas emissions and water footprint arising during the different stages of the product's life cycle or a facilities resource use will be identified and assigned to three different scopes, as introduced by the WRI (World Resource Institute) and the WBCSD (World Business Council for Sustainable Development) in their GHG Protocol.

3.2.1 System boundaries

The carbon footprint includes the greenhouse gas emissions that are released during different stages of the life cycle of cane sugar. The inputs and outputs are analyzed for every production stage, process or activity and the related emissions are calculated. The time boundary of the assessment is the year 2019.

The following stages in the life cycle of cane sugar are included:

- Stage 1: Farming
    - Energy consumption: diesel for tractors and other equipment
    - Soil emissions
    - Crop residue management
    - Fertilization
    - Crop protection
    - Irrigation
    - Transport to next stage

- Stage 2: Local processing
    - Energy consumption: electricity and diesel/petrol use
    - Packaging materials and waste
    - Water use and wastewater
    - Transport to next stage

3.2.2 Scopes

In line with the requirements of the GHG Protocol, the emissions identified within the system boundary and the different stages are assigned to three different scopes as follows:

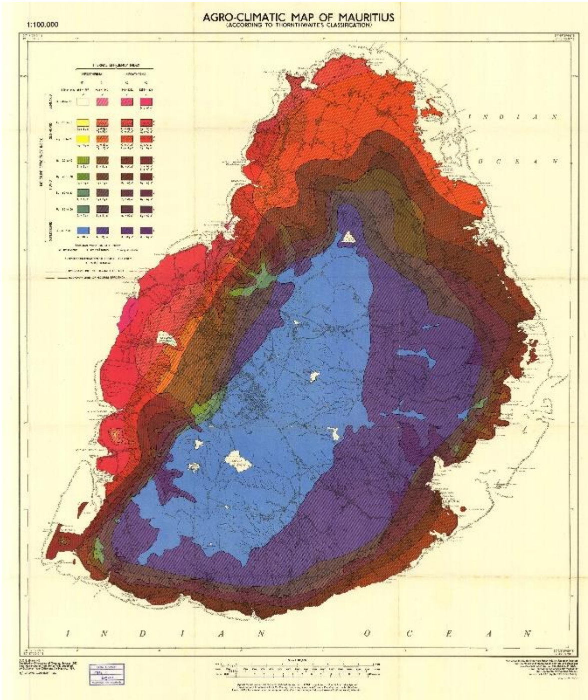
- Scope 1: Scope 1 emissions include the direct GHG emissions of a company or process. These emissions arise from sources that are owned or controlled by the process owners, e.g. a diesel use in the field.

- Scope 2: Scope 2 emissions include indirect GHG emissions arising from energy used in the production process. These are emissions from the generation of purchased electricity, heat or steam. Purchased electricity is defined as electricity that is purchased or otherwise brought into the organizational boundary of the process owner. Scope 2 emissions physically occur at the facility where electricity is generated.

- Scope 3: Scope 3 emissions include other indirect GHG emissions of the product. These emissions are a consequence of the process but occur at sources owned or controlled by external providers. Examples are purchased materials such as fertilizers or packaging, or transport emissions.

3.3 Farm clustering for a representative sample

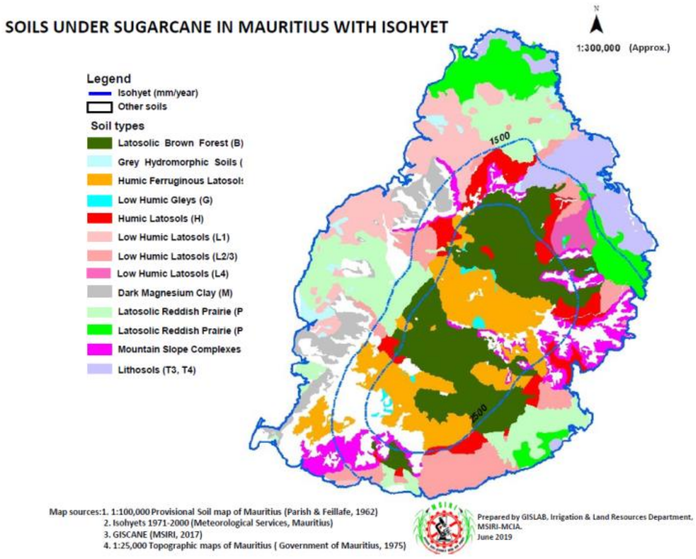
A total number of 4000 sugar cane farms was grouped into the main influential characteristic clusters by region connected to main climatic and geologic conditions. Other factors such as certification, farm size, productivity and grade of mechanization were rather inhomogeneous and therefore not explicitly grouped. A total of 38 farms was assessed.



The climate patterns in Mauritius show a clearly distinguishable pattern, whereas the soil types differ also within the defined centre-North-South clusters.

Three small producer organizations (SPOS), representing the three regions, were involved in choosing participating farms and in the respective data collection.

Farm size, certification and mechanization level was included in all of the cluster's questionnaires.



Clustering of farmer groups for the assessment

Cluster no.	1	2	3
GeoClimate	High precipitation and hilly terrain	Low precipitation and flat terrain	Low precipitation and hilly terrain
Names of regions/SPOS involved	Centre Petit Paquet MCS	North Century CCS	South Surinam Souillac CCS
n° and names of prevailing soil types	Lactosolic Brown Latosol	L Soil (Low Humic Latosols and Latosolic Reddish Prairie)	LBF- Lactosolic Brown Forest, HL- Humic Latosol
n° of farmers involved	268	114	132
n° of hectares involved	311	99	242
soil pH	pH 4.5-5.6	pH 5.15-5.20	pH 4.5-5.5
% small scale farms (<10 ha)	100	100	100
% high productivity farms (>70 - 75 TCH)	25	85,5	98,65
% average prod. Farms 70 - 75 TCH	75	10	0
% low prod. Farms (<70 - 75 TCH)	0	4,5	1,35
% farms with irrigation	0	83	12,39
Sample farms	**16**	**11**	**11**

Data sources

Wherever possible, primary data was used to carry out this carbon footprint. In case such primary data wasn't available, secondary data was used. In case the sources of this secondary data proved to be unreliable, assumptions were made.

In the case of uncertainty or several different data sources, the most conservative approach was chosen. That means the value causing the highest amount of emissions was taken for the calculation.

In general, it is advisable to use as much primary data as possible. Doing so, the actual emissions can be quantified in a more understandable way, and opportunities to improve efficiency can be easily identified.

For this assessment, all primary activity data was collected by local Fairtrade technicians on selected representative farms Mauritius at farming level, and remote questionnaires answered by the sugar mills on processing level.
Secondary data was used for the modelling of the transport as well as packaging material. The secondary data was taken from official databases e.g. DEFRA UK.
Assumptions are mentioned at the end of the results chapter.

4 Greenhouse Gas Inventory and Results

4.1 Common practices of sugar cane cultivation in the 3 clusters

Sugar cane is grown in a 7-year-cycle, with harvest taking place from June to December every year. Despite Mauritius having historically favoured green cane harvesting, the changing global economic environment has resulted in some farmers (around 15%) burning sugarcane before harvesting to remove leaves, weeds and other trash that delay harvesting and milling in order to avoid the costs associated with manual leaf stripping. In the course of Fairtrade trainings, however, farmers are sensitized as to the importance of green cane harvesting, which is more beneficial for soil biology. All investigated farms work conventionally, independent of whether or not they are Fairtrade certified.

Productivity and farm size

Productivity ranges from 40 to 100 tons/ha, whereas 70 - 75 t/ha can be considered as the viability threshold. The average size of the assessed farms is 1.1 hectares and the average yield is 71,2 t/ha. Farms in cluster 2 are the smallest, with an average of 0,8 hectares whereas the yields are the largest with an average of 92,8 t/ha.

Cluster:	Average crop area/farm	Average Yield t/ha	Dominating soil type	Soil drainage	SOM	Soil humidity	Irrigation
1	1,34	57,35	clay	poor	low	moist	0
2	0,76	92,76	mixed	good	mixed	moist	9 of 11
3	1,23	69,95	silt	good	mixed	dry	3 of 11
Grand Total	**1,14**	**71,25**					

Soil organic matter (SOM) in %

Generally, SOM is rather low.
- Cluster 1: majority below 1.72
- Cluster 2: some below 1.72 AND some 1.72 to 5.16
- Cluster 3: all 1.72 to 5.16

On average, cluster 3 has the highest SOM and cluster 1 lowest. Cluster 2 is evenly mixed. This correlates with soil type, cluster 1 is mostly clay and cluster 3 is mostly silt. Again, cluster 2 has got mixed silt/clay soils.

Nearly all farms in cluster 1 indicate to have poor soil drainage, 2 & 3 all indicate good drainage. pH is generally low (nearly 75% below 5.5).

Sugar grows well in deep, well-drained humid soils of medium fertility of sandy loam soil textures with a pH range from 6.0 to 7.7. The optimum soil pH is about 6.5 but sugarcane can tolerate considerable degree of soil acidity and alkalinity. Waterlogged, acidic and poorly drained soils are not suitable, which partly explains the lower productivity in Cluster 1.

Fertilization

No organic fertilizers are used. Nearly all farms indicate to use an NPK with an N=17%, P_2O_5=18%, K_2O=25%. Fertilizer use is on average 599 kg / ha, but it is around 80 kg / ha higher in cluster 2. The lower carbon footprint of fertilizer production in Cluster 2 will be further discussed in chapter 3.1.

Tillage

According to IPPC, practice changes of the past 20 years can be taken into account when it comes to agricultural practices which impact soil management. The great majority of farms have gone from conventional to reduced till, on average 10 years ago on 84% of the crop area. 3 Farms, all in cluster 3, went from reduced to conventional till on average 11 years ago on 55% of the crop area. This has a huge impact on overall emissions and is the main determinant of the agricultural emissions analysed.

Pesticides and herbicides

Only post-emergence pesticides are used with an average of 2 doses per year. No big difference here between clusters. The assessment did not distinguish between pesticides and herbicides usage, but as common practice it is assumed that also herbicides are being used in the sugar cane.

On-farm energy use

The only fuel used on farm is diesel. The average amount of diesel used / ha is a lot higher in cluster 2 with 247 liters /ha/year resulting in the highest carbon footprint on energy use. The others are around 120 liters/ha/year. Most (> 95%) planters' canes are manually harvested. However, around 50% is mechanically loaded. Irrigation mostly happens per gravity which does not influence the carbon footprint. One item not assessed by this footprint is that, even if irrigation enters farms by gravity (from a higher up basin for example), still often the water is pumped into that basin. This is now not accounted for, but this data might also not be accessible to the farmers.

Irrigation and agricultural water footprint

Cane cultivation zones vary from dry to superhumid, and 12 of 38 farms have irrigation, most of them in Cluster 2.

Cluster	Erosion risk*	Green WF/natural water use	Blue WF/ irrigation	Grey WF/ pot. water contamination	Measures
C1	high	1076,4 mm	0 mm	1,818 l/kg sugar cane	Increase productivity
C2	low	1004,4 mm	221,1 mm		Use efficient irrigation systems
C3	medium	1273,5 mm	123,5 mm		

* Estimated from available data

In C1, rainfall is sufficient for the crop most of the year. Only from mid-August to early November some irrigation can improve yield, but it depends also on the size of the sugarcane at that point. Therefore it makes sense that these farms have no irrigation, it also means that the farm-level blue water footprint equals 0. The green water footprint can be reduced by increasing productivity, which is mostly related to soil structure improvement. When soil structure is improved, available water can be used more efficiently also in the dryer season. Erosion potential is high due to the hilly terrain and high amount of rainfalls.

In C2, there are 9 farms with irrigation - average of 12,197 liters/ha (2 farms have indicated very high water use and increased the average quite a lot)

- 4 drip, 2 pivot, 3 rain gun

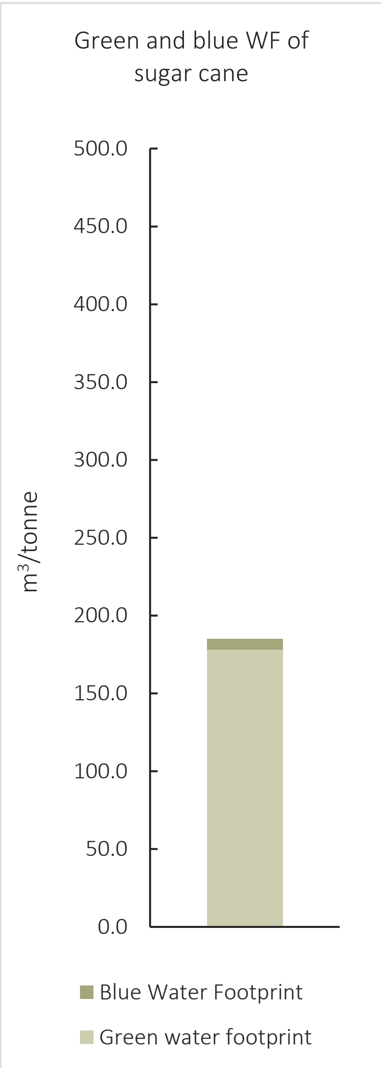
Interestingly the drip irrigation users are the biggest water users of all (10,000 to 30,000 liters /ha). Also the pivot users have higher water use (around 7,500 l/ha). Rain gun users have low water use (around 3,000 l/ha) due to water use restrictions, which do not apply to farms with drip irrigation. Being in a much drier area, crop water requirements exceed rainfall approximately from early April to late November. For those who do not have irrigation, this leads to lower yields but no blue water footprint. For those who have irrigation, the blue water footprint is 221.1 mm. Green water footprint is 1004.4 mm.

In C3, there are 3 farms with irrigation:

- average 2389 L / Ha
- all rain gun, low water use (around 2000 liters/ha)

In Cluster 3, precipitation is a little higher, but climatic circumstances also cause the crop evaporation to be higher. Therefore, the picture is comparable to Cluster 2. Farms without irrigation have no blue water footprint, otherwise it is 123.5 mm. Green water footprint is 1273,5 mm.

No clear trend can be found between blue water footprint and productivity.



The average green WF for Fairtrade sugar cane production in Mauritius is 178 litres per kg and the blue WF is 6.8 litres per kg sugar cane. While the green WF is similar to that of the US and China and therefore higher than the global weighted average of around 140 litres per kg, the blue WF is similar to sugar cane production in Brazil, China and Colombia and thus significantly lower than the global average of around 50 litres per kg (Gerbens-Leenes and Hoekstra, 2011)[5]. The reliance of Mauritian Fairtrade cane sugar production on surface and groundwater is thus generally comparatively small. Excluding the grey WF, the total WF of the agricultural production of Fairtrade sugar cane in Mauritius is slightly lower than the global weighted average.

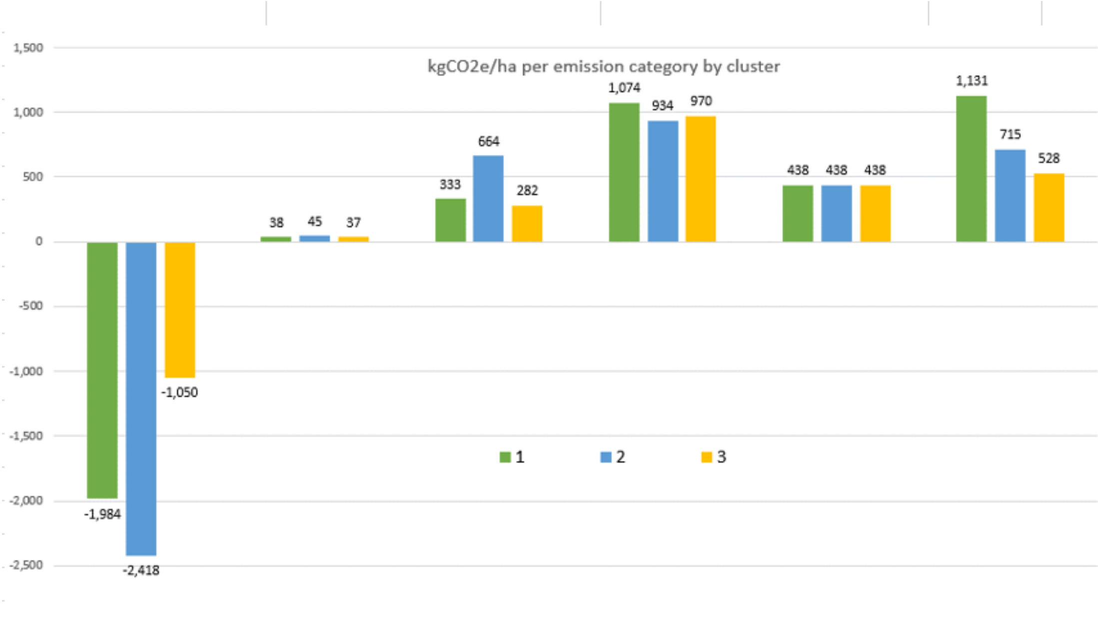
The grey WF of the agricultural production is 1,818 l/kg sugar cane and 19,239 l/kg processed sugar. That means that this amount of water is needed to dilute the pollutants to acceptable levels. The most critical agent with the highest value for the agricultural grey water footprint was DMA6, 2,4-D Sel Amine. There was no differentiation regarding grey WF between the different clusters. Finding suitable grey WF studies for the sake of comparison is challenging due to the extreme variability of results depending on the types of chemicals considered and, in this case, no suitable studies could be identified.

4.2 Carbon Footprint of Mauritian sugar cane cultivation

Emissions by category:

1) Carbon stock changes – accumulation or release of C in soil or biomass
2) Crop protection – emissions derived from applying pesticides
3) Energy use – emissions from diesel
4) Fertilizer production - emissions from NPK fertilisers*
5) Residue management - emissions from decomposition of residues in the field
6) Soil/fertilizer emissions – deriving from soil respiration in interaction with fertilizers

Overall Carbon footprints per ha and category for the 3 clusters



	Carbon stock changes	Crop protection	Energy use	Fertiliser production*	Residue management	Soil / fertiliser
1	-1,984	38	333	1,074	438	1,131
2	-2,418	45	664	934	438	715
3	-1,050	37	282	970	438	528

Cluster	Average GHG emissions /kg CO_2e ha^{-1}	Average GHG emissions /kg CO_2e kg^{-1} sugar cane	Average GHG emissions /kg CO_2e kg^{-1} processed sugar
1	1030.2	0.018	0.180
2	378.0	0.002	0.020
3	1205.4	0.019	0.190
Average across clusters	871.2	0.013	0.130

Emissions per ha and kg

Per hectare, C2 has the lowest emissions with 378 kg CO_2e/ha. C1 and C3 have 1030.2 respectively 1205.4 kg CO_2e/ha respectively.
As Cluster 2 is also most productive, with an average yield of 93 tons/ha, the agricultural emissions per kg are lowest with 0,002 kg CO_2e/kg. C1 and C2 have emissions of 0,018 and 0.019 kg CO_2e/ha. Sugarcane is a highly productive crop, leading to very low emissions per kg.

***Fertilizer production and emissions**

The biggest source of GHG emissions is fertilizer, both production and (de)nitrification processes that cause NO_2 emissions. Most farmers indicate no source, but those who do indicate China. Production emissions from fertilizer is a big impact, therefore important to consider where it comes from. As currently not all producers were indicating its origin and the Cool Farm Tool allocates lower standard emission factors to NPK fertilizers with unclear origin than for those produced in China, the result showing differentiated fertilizer production emissions per cluster may be a little unprecise. It is safe to say that all clusters have approximately equal emissions from fertilizer production, possibly C2 even slightly higher due to higher fertilizer use, and that it may be useful to choose other origins than i.e. China.

Interesting observation is that emissions from soil/fertilizer are much higher in C1 and lowest in C3. The explanation can be found in the state of the soil. Soil characteristics such as SOM are generally much better in C3 than C1, whereas C2 is in the middle. This likely causes differences in NO_2 emission which play an important role.

Residue management

Crop residues are left on the field after harvest. This induces soil respiration in the form of CO_2 and NO_2 but also helps to build up soil organic matter which is reflected in the carbon stock changes.

Carbon stock changes

The main explanation for the carbon footprint differences between the clusters is not necessarily found in the emissions, but more in carbon sequestration. All 3 clusters show a negative value regarding Carbon stock, which means that they do store carbon in the soil. Tillage change during the past 20 years plays a big role, whereas changing from conventional to reduced or even no-till results in more C sequestration in the soil. In Cluster 2, most land has undergone a conversion from conventional to reduced tillage followed by Cluster 1. In Cluster 3, some farmers have actually done the opposite, going from red to conv till. Therefore, less carbon sequestration took place in C 3. SOM also plays a role in C sequestration – the more SOM in the soil, the faster biomass can be incorporated.

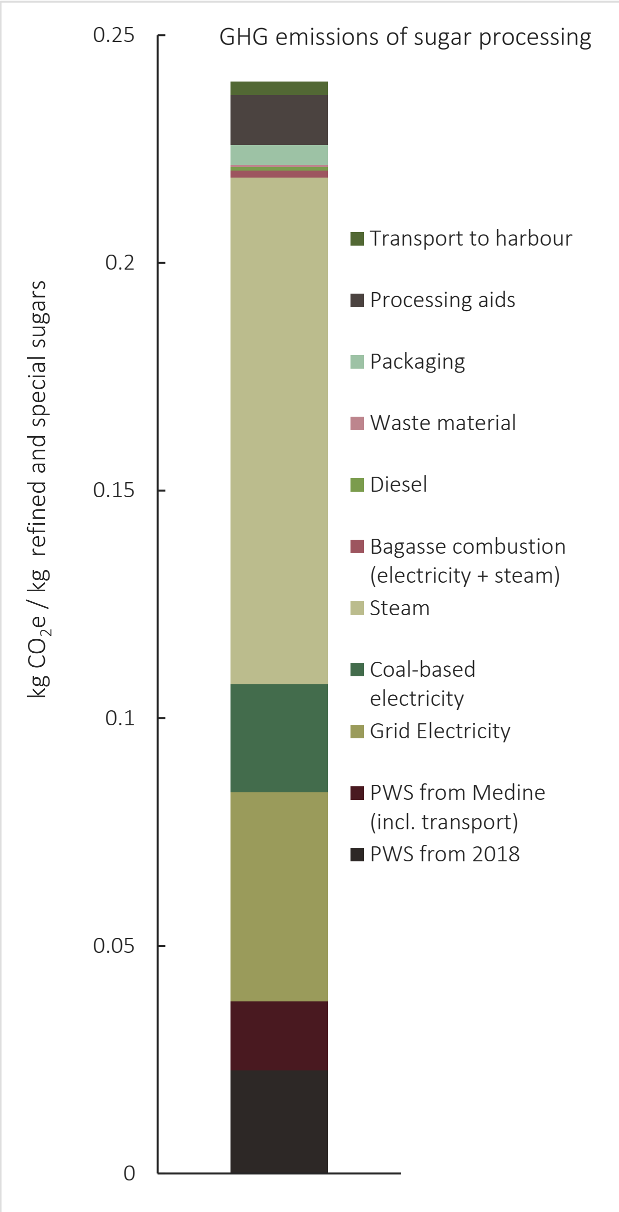
Overall, Cluster 2 performs best on productivity and footprinting level. The reasons for productivity may be summarized in good soil quality, high inputs (mechanization, irrigation and fertilizers), combined with a well-drained soil with reasonable SOM which is able to sequester more carbon.

Please note the chapter “Assumptions made and system limitations” further below.

4.3 Carbon footprint of sugar processing

As is the case for many other food items that require considerable processing, the latter can represent a substantial portion of the climate and water related impacts in the production of cane sugar. Considering the processing stage is therefore essential when attempting to obtain a complete picture of the impact of Fairtrade cane sugar production in Mauritius. In order to quantify the contribution of the processing stage to the overall carbon and water footprint, the Alteo and OMNICANE refineries, both Mauritius-based producers of Fairtrade cane sugar, were investigated. Emissions from transport of the finished product to the harbour from which it is shipped overseas was included in the processing stage, as the refineries are in charge of that transport. The transport of sugar cane from farms to the refineries is considered later on when the overall footprint of Fairtrade cane sugar from Mauritius is presented.

Processing Carbon Footprint



For both refineries, the extraction and refining process of an entire year was analysed for potentially relevant sources of GHG emissions. The needed data was then collected directly from the processing companies. The assessment is based on data for the calendar year 2019. Using conversion factors provided by the UK Department for Environment, Food and Rural Affairs (Defra), the International Energy Agency (IEA) as well as additional sources, the emissions for each source were calculated. These were then allocated to the output of refined white and special sugars based on their share of the overall revenue generated from the refinery products. The revenue from refined and special sugars amounted to roughly 95% of the overall revenue of sugar cane derived products, so that 95% of emissions were attributed to these final products. The emissions resulting from trucking the sugar to the harbour were entirely allocated to sugar.

The figure to the left shows the weighted average processing emissions by source per kg refined and special sugars of the refineries. It is quite clear that the consumption of coal-based steam, a by-product of electricity generation in the adjacent bagasse- and coal-fired cogeneration plants, is the largest single source of processing-related GHG emissions. The emissions associated with steam and electricity consumption would be even higher if it were not for the large share of the cane-crushing by-product bagasse in electricity and steam generation, which merely causes a small amount of N_2O emissions. All of the CO_2 released in the combustion of bagasse and cane trash has recently been captured by sugar cane production and is therefore considered carbon neutral. The emissions embodied in bagasse are already accounted for in the agricultural production component.

4.4 Overall carbon and water footprint

In order to obtain representative carbon and water footprints for Fairtrade cane sugar from Mauritius, the climate and water performance metrics of the three clusters and of the two sugar processing plants assessed were averaged. For the latter, a weighted average was used based on the sugar output of the refineries.

Carbon footprint

The figure below shows the carbon footprint of Fairtrade cane sugar from Mauritius. At 0.36 kg CO_2e per kg sugar (see table below) it is significantly better compared to footprints generated for cane sugar from Australia (>0,5 kg CO_2e per kg cane sugar) (Renouf et al., 2008)[6] and a generic carbon footprint for cane sugar (0.43 kg CO_2e per kg cane sugar) (Rein, 2010)[7]. The additional emission reduction by displacement of grid electricity due to renewable energy generated from bagasse in surplus of the refineries' own demand is not accounted for in these numbers. This positive aspect of cane sugar production in terms of climate impact, i.e. the combustion of bagasse for renewable energy generation, will be discussed in the following section.

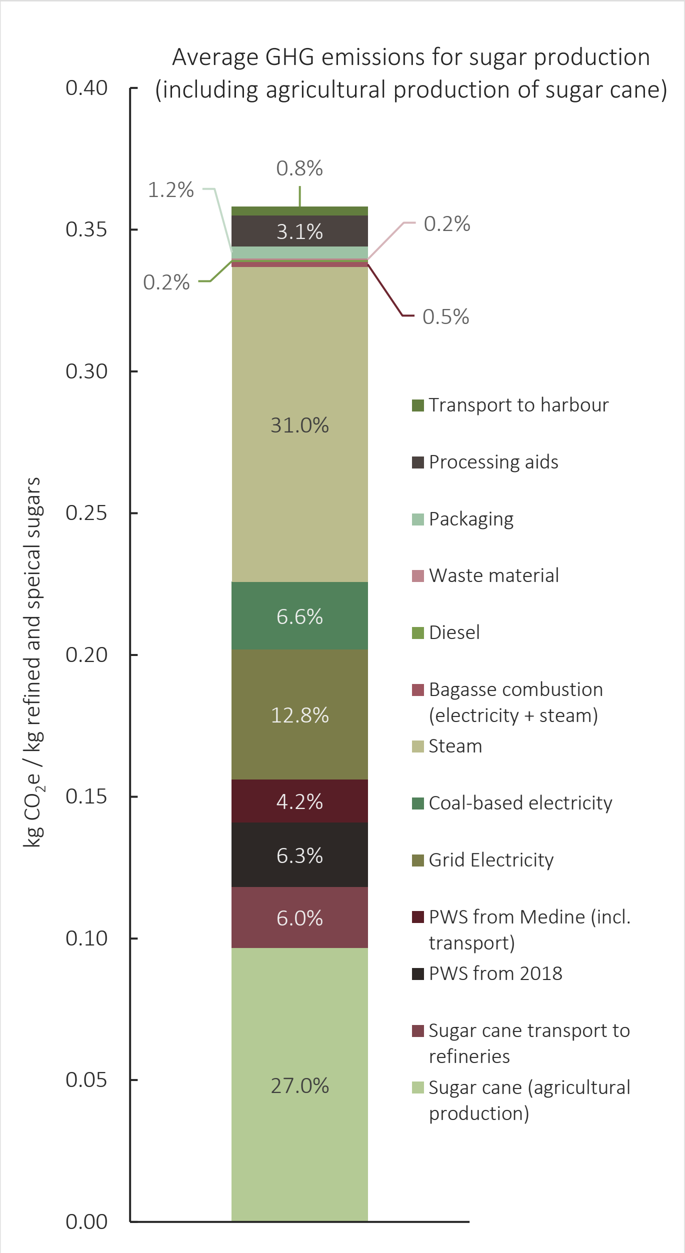


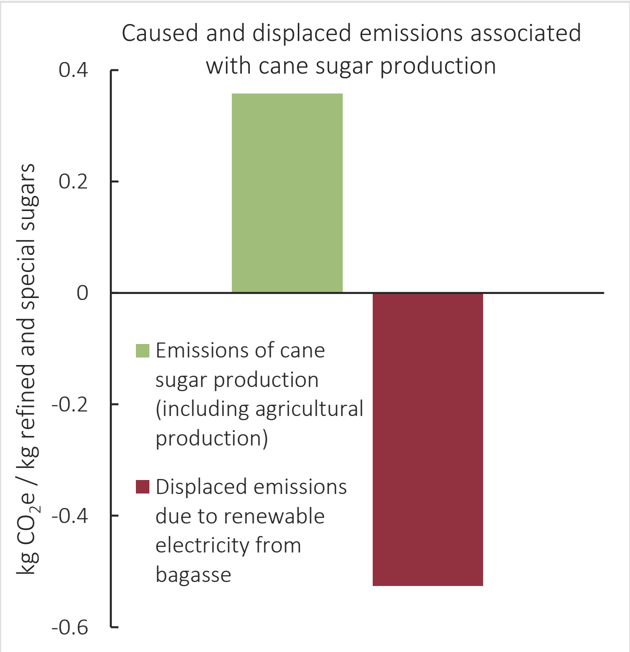
Table 1 Farm to harbour emissions of sugar cane derived Faitrade refined and special sugars from Mauritius by source.

Source	Emissions/ kg CO_2e per kg sugar
Transport to harbour	0.003
Grid Electricity	0.046
Coal-based electricity	0.024
Steam	0.111
Bagasse combustion (electricity + steam)	0.002
Diesel	0.001
Packaging	0.004
Processing aids	0.011
Waste material	0.001
PWS from Medine (incl. transport)	0.015
PWS from 2018	0.023
Sugar cane transport to refineries	0.022
Sugar cane (agricultural production)	0.097
Total	**0.358**
Surplus electricity from bagasse	-0.526

System Expansion

The displacement of conventional electricity is an important benefit of an integrated cane sugar production process where the renewable energy embodied in the fibrous remains of the sugar cane plants are used in an efficient way. Not only can the energy released from bagasse be fed back into the industrial process itself, but it also contributes to climate change mitigation beyond that.

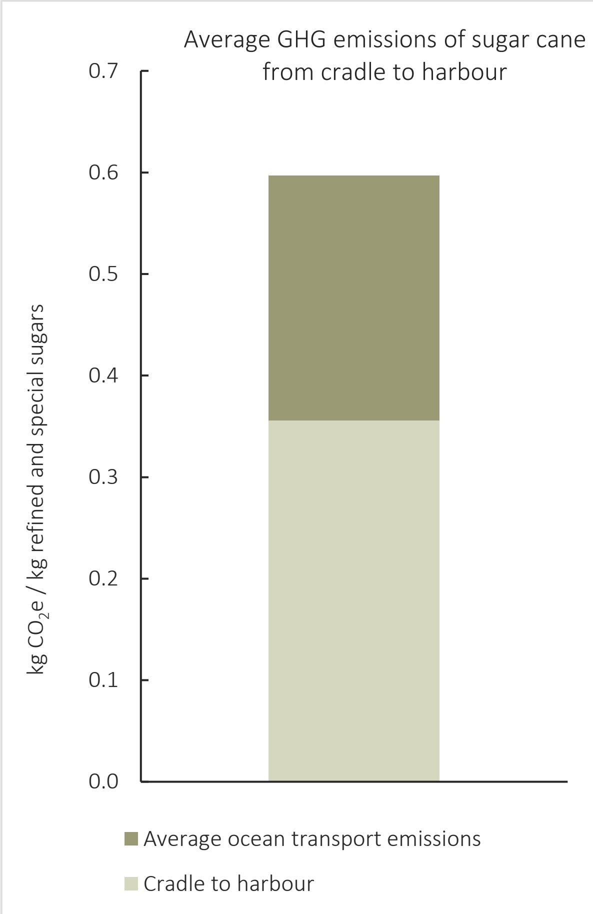
Bagasse, the most important by-product of sugar cane processing, as well as cane trash can be combusted for energy generation. As renewable biomass serves as the feedstock input, the energy produced from them is categorized as renewable and can as such be accounted for in the carbon footprint of refined sugar by using the system expansion method. This is commonly applied when one or more co-products of a production process is used in a way that other materials, resources or energy sources with higher emission factors can be displaced. The difference in emissions between those caused by the displaced material or energy source and that associated with the use of the co-product can then be subtracted from the main product's footprint. The efficient use of bagasse by the two refineries assessed leads to a negative overall carbon footprint when



applying the system expansion method, meaning that more emissions are avoided by displacing mainly fossil fuel-based energy sources for electricity generation than are emitted in sugar cane production, processing and inland transport combined. The diagrams show quite clearly that the emission reductions that can be attributed to renewable electricity generation from the co-products of cane sugar production outweigh by far the overall emissions released within the defined system boundaries. Based on the data and information that was made available for this assessment, the displacement of emissions outweighs emissions caused by all stages occurring in Mauritius combined by 0.17 kg CO_2e per kg sugar.

Ocean Shipping

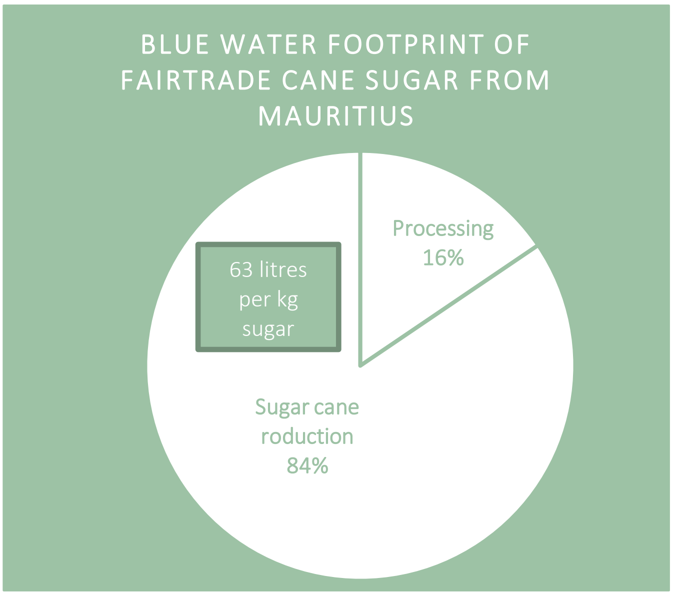
As an additional step to the core scope of the study, the emissions associated with the ocean transport of sugar to Europe were determined. An unweighted average across the most important shipping routes from Mauritius to Europe via the Suez Canal and transport on a container vessel was assumed to calculate these emissions. The following European ports of destination were considered: Felixstowe, Genoa, Antwerp, Hamburg, Las Palmas, Rotterdam, Liverpool, Malmoe. With 0.24 kg CO_2e per kg sugar, ocean transport from Mauritius to Europe would constitute the single largest emission source considered in this assessment. Adding this to the carbon footprint of sugar results in a total footprint of around 0.59 kg CO_2e per kg, exceeding the 0.53 kg CO_2e of emissions displaced on average by bagasse-based electricity.



Total water footprint

Data and information regarding the chemical status of the wastewater generated is insufficient for calculating a grey WF for the processing stage and only the agricultural production stage entails a green WF, which is why the total water footprint can only be carried out for the blue WF.

The graph to the right shows the distribution of the overall blue water footprint of Fairtrade cane sugar from Mauritius. On average, water consumption (mainly river water) of the processing stage amounts to 10 litres per kg sugar. Agricultural production of sugar cane has a blue water footprint 6.8 litres per kg of sugar cane, which is equivalent an average of 67 litres per kg sugar. However, since all of the wastewater leaving the refineries is utilized for the irrigation of sugar cane crops, this lowers the net irrigation of sugar cane to around 53 litres per kg sugar. All of the wastewater exiting the refineries is used for irrigating sugar cane, resulting in a circular system that ensures efficient use of water resources. The documentation procedures are still in development so that in the future, more robust data might be available. The net overall blue water footprint is therefore around 63 litres per kg sugar, 84% of which are due to sugar cane cultivation. Therefore, the largest potential for decreasing the water footprint is to use irrigation as efficiently as possible and implement other good agricultural practices.



4.5 Assumptions made and system limitations

Agriculture

The biogenic mass of the aboveground growing sugar cane is not accounted for, as it is removed from the field and processed.

The model currently does not account for the potential soil SOM build-up by the decomposition and re-growth of the roots after each harvest. This would potentially have a positive effect in C sequestration which is currently not being accounted for due to the limitations of the used online tool.
Literature states that sugar cane can effectively store high amounts of stable C in the soil in the form of 'plantstone carbon'. As the Cool Farm Tool does not have a corresponding algorhythm, 0,66 tonnes CO_2e per hectare have been added to the carbon stock based on the article from Southern Cross University stating that this amount is sequestered for sugarcane specifically (1). This reduces the emission calculated by the Cool Farm Tool by about 40%.

One farm from Cluster 1, Mahabir Taramatee, has been excluded from calculations due to a crop area size that is way too big compared to entered productivity levels. This data was obviously not realistic, disturbed the outcomes too much and could not be corrected in hindsight. Therefore a total of 38 farms has been analysed.

Processing

Several assumptions had to be made for calculating the GHG emissions of the processing and transport to harbour in order to fill data gaps and for the sake of feasibility:

- Emission factors could not be found for all processing aids, so that general products in the use category or similar chemicals were used, which is common practice.
- The freight capacity of the HGVs used to transport sugar cane from the farms to the refineries was not provided. Therefore, a freight of 10 tonnes per HGV was assumed. Furthermore, the return trip of the empty HGVs to the farms was accounted for as well, as it was assumed that the single purpose of the HGV trips was to deliver sugar cane to the refineries.
- Even though not all of the sugar output of the refineries is shipped to the harbour for export, it was assumed that all the refined sugar is transported to the harbour as the footprint of 1 kg sugar from production until the harbour was the subject of the assessment. In this case, transport was assumed to be one way from the refineries to the harbour in HGVs that can carry 25 tonnes of sugar. It was also assumed that the HGVs are always fully loaded.

5 Recommendations for mitigating the footprints

Green cane harvesting

The first step for increasing the resilience of the system has already been taken: through the introduction of production indicators in the Fairtrade standards and awareness campaigns on good agricultural practices, a significant reduction of cane burning was achieved despite the incentive of avoiding the extra costs associated with manual leaf stripping. This positive trend should be continued towards a complete implementation of green sugar cane harvesting.

Reducing tillage

Sugar cane grows better on a non-compacted soil, but whenever possible tillage should be reduced and replaced by other types of loosening via biomass or cover crops. This accounts particularly for Cluster 3, as their emissions have worsened due to returning to conventional tillage. Reduced tillage also helps to maintain soil organic matter levels, which in return can help soil structure, making conventional tillage less necessary.

Keeping soil always covered

Leaving the crop residues on the field instead of burning them may induce some soil emissions but is mandatory in order to feed the soil micro-organisms and to build up soil organic matter. In the dry season, the crop residues protect the soil as a mulch layer; keeping weeds down and remaining moisture in the soil. If they're still left when the rainfalls arrive, they protect the soil from erosion via runoff, capping and from excessive evaporation.

Introduce organic fertilization by returning residues from sugar mills to the soil

Brazilian examples have shown that spraying vinasse as fermented by-product of cane processing onto the residues increases residue degradation and soil microbial activity due to its rich sugar and mineral content. Test results to date indicate that there are no harmful impacts to the soil and ground water at doses below 300 m^3 / ha.[8] However, care should be taken and soils should be tested for its effect as vinasse has got a low pH and may contain unwanted residues from processing like sulfates. Also, the incorporation of presscake (scum) can have positive effects and add to soil build-up and replacement of NPK fertilizers.
In the case of Mauritius Fairtrade sugar cane farmers, scum availability is very limited and has to be purchased commercially.

Erosion prevention

Farms with hilly terrain, high precipitation and high rainfall are prone to soil water erosion. Especially C1 is expected have problems as soils are reported to have bad drainage. Structural liming helps to improve the structure of clay soils and raises the pH to a higher level.
C3 also encounters higher precipitation and hilly terrain, whereas the soils may be absorbing the water easier due to their high organic matter content.
Other classical erosion prevention methods are mulching, reducing tillage, increasing SOM, cover crops, terracing, ploughing/planting across the slope, and installing i.e. vetiver grass hedges as natural water barrier.

Keeping soil surface possibly rooted

It may be worth trying out a perennial leguminous undersown crop. Introducing low-growing *desmodium* varieties after tillage / with planting can act as a living mulch as it suppresses weeds, adds nitrogen, protects the soil from erosion, keeps the moisture, and repels pests such as the stem borer. It will also loosen the soil and enrichen it with organic matter via its root system. *Desmodium* needs well-drained soils with a pH higher than 5 and is quite shade-tolerant.

Picture: PIP manual from COLEACP

This practise is successfully used with in a mulch and push-pull system in maize, with napier grass at the sides to attract pests away from the crop itself. Cover crops would have to be installed directly after ploughing along with the planting, so that the roots can penetrate into and stabilize the loosened soil.
Also integrating deep-rooting and/or leguminous crops after a sugar cane life cycle, either in a full crop rotation or as intercrop, will be helpful to add to the soil organic matter. Crop residues and especially roots should always be left in the field and possibly incorporated.

Raise the pH to approx. 6,5

The pH of most farms is below 5,5. Sugar cane tolerates low pH, but certain nutrients such as P, K, C and Mg are more likely to be available at a higher pH. It will not help to add them via fertilization as long as the pH stays low. Increasing SOM will also buffer the pH levels, but to start off with liming will be required if pH is less than 5,0.
What's more, in acid soils conditions (pH less than 5,2), Aluminium replaces Calcium on cation exchange capacity and Al toxicity may occur. In sandy soils having a very low cation exchange capacity, lower concentrations of Al in the soil solution may already cause toxicity problems. High applications of K may induce Ca deficiency in acid soil containing low Ca levels[9]. Better than replacing one single soil mineral nutrient is to increase the buffer capacity of the soil by liming and adding organic matter. Individual soil testing will help to give a more detailed advice here.

Pay attention to salinity

Sugarcane is regarded as a relatively salt sensitive plant which should be considered when it comes to irrigation. In the case of Mauritius this is apparently not a problem.

Check and change fertilizers origins

The production of synthetic N fertilizer is very energy-intensive. According to the origins of the fertilizers and the assumed respective energy sources, the emission factors per pk product change. It could be verified if choosing a more local origin or an origin from a country using a high percentage of renewable energy would make a difference.

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