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Life cycle assessment of ethanol production from molasses in Ethiopia

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Abstract: Ethanol produced from different raw sources is used for a wide range of purposes, including as vehicle fuel. In Ethiopia, around 20 million liters of ethanol is expected to be produced from molasses every year by two dominant sugar factories (Metehara and Fincha). The main objective of this study is to assess the environmental effects of ethanol production from sugarcane molasses during the period 2016 to 2017. The functional unit is based on 1000 L-ethanol produced. Calculations were performed using the ReCiPe life cycle impact assessment method considering both midpoint and endpoint indicators. The result shows that the cultivation stage contributed the most to climate change (54.5%), photochemical oxidant formation (80%), and land use (99%) impact categories due to fertilizer production, cane burning and decomposition and application of fertilizers. On the other hand, ethanol production had a greatest contribution for resource depletion (63%), terrestrial acidification (92%), terrestrial ecotoxicity (99%), marine eutrophication (92%) and ozone depletion (84.4%) due to consumption of light fuel for ethanol plant and waste came from vinasses discharges into river. The endpoint indicators, however, showed that the cultivation stage was the major contributor to all the life cycle impacts from ethanol production. The outcome of this study is expected to be beneficial to the sugarcane sector and ethanol production, environmental and design engineers, and for academics and policymakers.

Keywords: Life Cycle Assessment (LCA), Sugar cane, Molasses, Ethanol.

1. Introduction

Currently, there has been an increase in the production of petroleum fuel due to increased demand from the consumers. Beside other factors, the major issue is being a source of air pollution [1]. Other factors include the increase in cost over time with shortage of resources which indicate the need to look for other alternative fuel to substitute fossil fuels [2]. Bio-ethanol is one of the economically friendly alternative fuels that can be used to substitute gasoline without changing petrol engines with current fueling infrastructure [3-4]. Ethanol is a clear liquid phase alcohol that is produced by fermentation and used for wide range of purposes. [4]. Bio-ethanol has been shown to have better environmental performance than gasoline in many studies in the literature. Also, combustion of fuel ethanol results in comparatively lower emissions of volatile organic compounds and carbon monoxide [4-5].

The increase in energy demand for transportation has led to a search for alternative energy sources in Ethiopia. Ethanol from sugarcane is one of the promising candidates. The production of ethanol in Ethiopia is directly integrated with sugar factories. The total known land for sugarcane cultivation in Ethiopia is about 700,000 hectares, with the expected potential to produce one billion liters of ethanol though the current annual production capacity is around 20 million liters of ethanol. Moreover, at present only two of the sugar factories, Fincha and Metehara, are producing bioethanol. It has become preferred due to its potential similarity on the appropriate characteristics of fuel petroleum products at competitive price [6-7].

Ethiopia is a developing country, however the majority of population is living in rural areas and their activities are mainly agricultural related [8]. Ethiopia's economic growth relates to exported agricultural products i.e. coffee, oilseeds and flowers. In 2010, the Environmental Protection and Forestry Agency in Ethiopia reported that more than 85% of greenhouse gas (GHG) emissions are from the agricultural and forestry sectors followed by power, transport, industry and buildings, contributing about 3% each [9].

Since the last two-decades, the Ethiopian economy has transformed from agricultural to industrial sectors. Therefore, to regulate the environmental burdens from every activity, Ethiopia has set a plan to mitigate the environmental impacts. The Green Economy Strategy is one of the project plans towards this aim. Based on this approach, they recognized and arranged more than 60 enterprises are identified, which will enable to achieve the development goals while limiting greenhouse gas emissions in 2030 at today's levels (150 MtCO_2 eq) [8-9].

This study has aimed at (i) carrying out an environmental life cycle assessment of ethanol production in two major sugar factories in Ethiopia (Metehara and Fincha) based on molasses and (ii) suggesting improvements to reduce the negative impacts in current processes by showing at which life cycle stage has more environment burdens.

2. Materials and Methods

Basically, this study focused on the environmental sustainability assessment of ethanol using the life cycle assessment method following the principles outlined in ISO14040:2006 and ISO14044:2006 [10-11]. Life cycle impacts are calculated from the inventory data during the year of 2016-2017 by using the ReCiPe 2016 life cycle impact assessment methodology at the midpoint and endpoint level. All the inputs and outputs were considered during the production of fuel, molasses-based ethanol, in the two major sugar factories (Metehara and Fincha) in Ethiopia.

2.1. Goal and scope definition

The goal of this paper is to present the life cycle assessment of the fuel ethanol based on molasses, in Ethiopia, based on inventory data collected from both sugar factories (Metehara and Fincha) i.e. those currently producing fuel ethanol. Then different environment impact potentials at various stages of fuel production were assessed. After impact analysis, the results were interpreted and pathways suggested improving the environmental sustainability of the sector. The final output result is expected to be important for the sectors working in the production of ethanol fuel and an inspiration for policy makers as well.

The scope of this study includes sugarcane farming, sugar milling, ethanol production and transportation. The raw materials, chemicals and other resources used in the inputs and the product, byproducts, wastes and emissions in the outputs were considered. The impact categories considered for this study are global warming, photochemical oxidation formation, terrestrial acidification, marine eutrophication, terrestrial ecotoxicity, land use, resources depletion and ozone layer depletion.

2.2 Functional unit

The functional unit for this study has been defined as producing 1000 liters of fuel ethanol based on molasses.

2.3 System boundary and data sources

The system boundary for ethanol production is shown below in Figure 1. The boundary is considered in three major operating activities: (i) *cane farming, (ii) sugar mill and power plant, (iii) ethanol production* and transportation.

2.3.1. Sugar cane farming

At the first stage of cane cultivation and harvesting, several steps are involved including land preparation, planting, crop maintenance (fertilizing, weeding, watering), and harvesting. It is a cropping of sugar cane rotation with one new planting followed by one to four (up to seven) ratoons. Harvesting is at the age of 13 months or before the sucrose level 20 Degrees Brix. These activities are controlled by the Agricultural and Cultivation and Harvesting Office [12-13]. All chemicals, fertilizers and other inputs used are recorded regularly and meticulously. Total diesel fuel used for all intermediate transportation for both the sugar factories (entire chain) during the period of 2016-2017 was recorded. The harvested sugarcane was transported to the sugar mill within 24 hours. In Ethiopia, sugarcane is transported to the mill by using large size trucks. The emissions are considered both for the transportation of cane delivered from the farm to the mill and the return trip when the trucks holding the filter cake from milling to the farm.

2.3.2 Sugar milling (molasses generation)

In the mills, the first process starts with cleaning and washing then reducing the size of cane by using hammer mill machine. Then the cane is squeezed under high pressure between three successive rolls. The extracted liquid juice is then transferred to a series of processing stages: extraction of juice, clarification and filtration, evaporation and boiling, crystallization and centrifugal separation which is then followed by drying, and packaging. This section has two key co-products (i) a sticky black syrup termed as molasses, which is the main raw feedstock for ethanol production and (ii) the fibers formed after the extraction of juice collectively called bagasse, which goes to the power plant and used as fuel for steam and electricity generation [14-15].

2.3.3 Ethanol conversion

Molasses is the only raw material used for production of ethanol in Ethiopia. Feed molasses contains about 50% of the total sugar. Generally, the ethanol plant consists of four major processing steps, viz., molasses treatment, fermentation, distillation and molecular sieve dehydration [14-15].

2.4 Allocation

In Ethiopia, milling processing factories are designed and operated in such a way that the different processing stages to get and maximize the profit of sugar production. The Ethiopian government has set plans to blend fuel ethanol with gasoline to create environmentally friendly fuel as well as to save the expenditure of currency for importing fossil fuels. In this study, the economic allocation procedure is used to share the environmental burdens from sugarcane cultivation and sugar milling between sugar and molasses. The calculations of the allocation factors are shown in Table 1.A and 1.B.

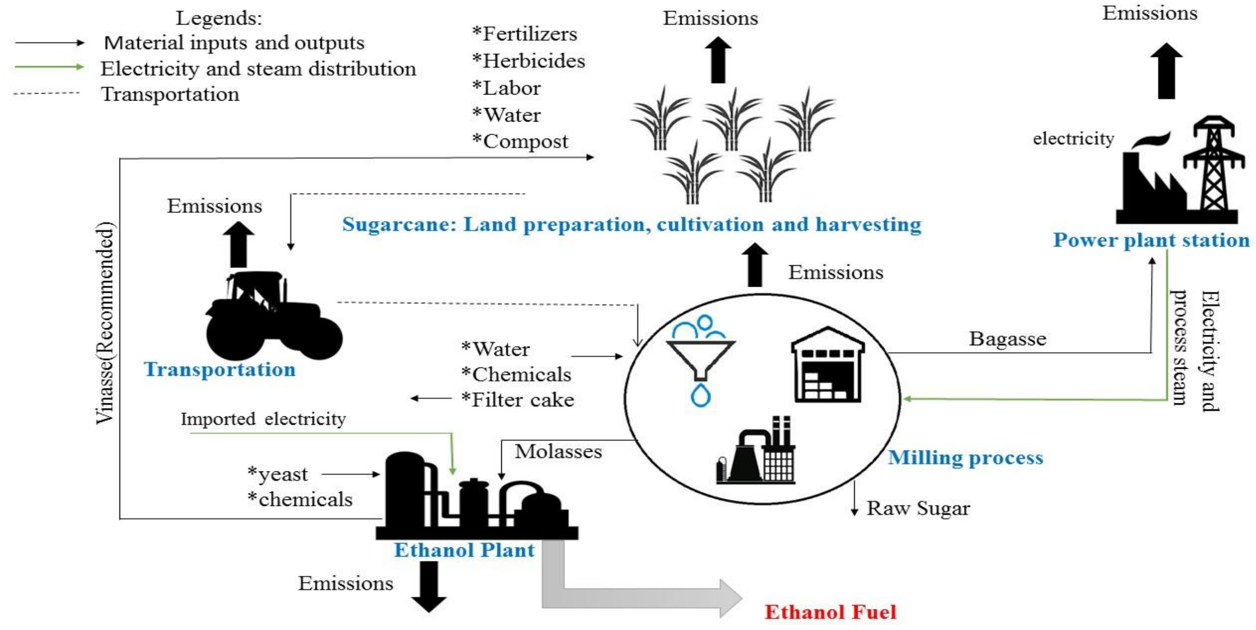

Figure 1. System boundary of molasses-based ethanol production.

Table 1.A. Allocation factors for Metehara factory.

Products	Amount in kg *	Economic allocation	
		Price ETB/kg **	Allocation Factor ***
Raw Sugar	78,000,000	12	0.92
Molasses	39,245,000	2.1	0.08
Total			1.00

*Produced raw sugar in Metehara factory in the year 2016-2017

**Price based on interview (January 2018)

***Allocation factor = $(yield_A*price_A)/((yield_A*price_A)+(yield_B*price_B))$

The allocation ratio for sugar and molasses was 0.92 and 0.08 respectively for the Metehara factory.

Table 1.B. Allocation factors for Fincha factory.

Products	Amount in kg *	Economic allocation	
		Price ETB/kg **	Allocation Factor ***
Raw Sugar	161,000,000	12	0.93
Molasses	70,310,000	2.1	0.07
Total			1.00

* Produced raw sugar in Fincha factory in the year 2016-2017

** Price based on interview (January 2018)

*** Allocation factor = $(yield_A * price_A) / ((yield_A * price_A) + (yield_B * price_B))$

For the Fincha sugar factory, the economic allocation ratio was 0.93 and 0.07 for sugar and molasses respectively.

2.5 Life cycle inventory analysis

The input and output data including raw materials, energy supply, and emissions to the environment as illustrated in system boundaries in Figure 1 were compiled. The following phases were considered: cane cultivation, transportation (field to sugar mill and return), sugar milling, electricity generation and ethanol production during the year 2016/17. All the data which were relevant to the inputs and outputs of the system boundary were taken from two sugar factories (Metehara and Fincha) in Ethiopia.

Cane harvesting

The average sugar cane production area was recorded as 6,500 ha for Metehara and 11,500 ha for Fincha sugar factory. The input chemical fertilizer used was urea. The herbicide used for weeding was 2-4 Dimethyl amine. Diesel was also used in tractors and trucks for land preparation and planting the cane seed as well as for transferring the produced sugarcane to factory. Since farmers using irrigation were fewer in number, cultivation was assumed to be rain fed. Here in this 45% of cane trash was burnt in open air in Metehara and Fincha sugar fields. All the input and output data that were collected from both sugar factories are presented in Table 2 below [12-13].

Transportation

In all the life cycle assessment stages, diesel propelled vehicles were used to provide for transportation. But both sugar mills have different systems for recording fuel consumption as shown in Table 3.A and 3.B. Transportation used for transporting cane to sugar mill and filter cake to cane field as a fertilizer are included in this section [14-15].

Sugarcane milling

At this life cycle stage, the produced sugarcane was converted into sugar, molasses and bagasse. The molasses is used as a raw material for ethanol production, while the bagasse is internally used as an energy input for the milling stage. For this reason, only molasses is considered as a co-product. It should be noted that the chemicals used in the sugar milling process, are not allocated to molasses because they are only used for sugar production [16-17].

Table 2. Sugarcane cultivation data 2016/17.

Inputs data	Amount		Unit	Outputs data	Amount		Unit
	Metehara	Fincha			Metehara	Fincha	
Cane yield	137	110.7	t/ha	Cane delivered	874,250	1236250	t/ha
Herbicides	6	7	kg/ha	Cane trash	148,645	209,791	tonne
Fertilizer(urea)	430	436	kg/ha				
$Fe_2SO_4.7H_2O$	30	41	kg/ha				
Human labour use	135	138	Man-day/ha				
Water	23,180	19,000	m^3				
Energy	4560	5338	MJ				

Table 3.A Fuel consumption in Metehara sugar factory 2016/17.

Year	Diesel (L) used for					Total diesel used (L)
	CAMECO truck (harvesting)	D4 (Isuzu)	Tractor	Bus and motors	Supervision vehicle	
2014/15	165,209	92,425	522,107	31,584	14,999	826,324
2015/16	185,955	117,130	601,787	35,918	17,254	958,044
2016/17	224,773	116,657	339,227	28,857	13,739	723,253

Table 3.B Fuel consumption in Fincha sugar factory 2016/17.

Activities used	Area (ha)	Fuel consumption (L/y)	Fuel consumption L/ ha
Land preparation	12,602	315,050	25
Cultivation	3,368	23,580	7
Harvesting	11,536.06	1,268,966	110
General transport	-	60,621	
Total diesel in L		1,668,217	

Table 4. Material/Chemical and Energy inputs and outputs in sugarcane milling.

Inputs	**Amount**		**Unit**	**Outputs**	**Amount**		**Unit**
	Metehara	Fincha			Metehara	Fincha	
Sugarcane delivered	874,250	1,236,250	tonne	Sugar	78,000	161,000	tonne
Lime	1.24	1.38	kg/t cane	Molasses	39,245	70,310	tonne
Sulphur	0.37	0.42	kg/t cane	Bagasse	287,950	371,110	tonne
Caustic soda	0.079	0.08	kg/t cane	Moisture content of bagasse	50.04%	50.01%	
electricity (self-produced)	28	45	GWh	Generated steam	500,945	708,371	t/y

Table 5. Material/Chemical and Energy inputs and outputs in ethanol plant.

Inputs	**Amounts**		**Unit**	**Outputs**	**Amounts**		**Unit**
	Metehara	**Fincha**			**Metehara**	**Fincha**	
Molasses	39,245	70,310	ton	Electricity	14.4	21.6	GWh
Yeast	0.02	0.02	kg/L-ethanol	Ethanol	8,000	12,000	m^3
Total ammonia (as N)	20	20	mg/L-ethanol	Vinasse	13	13	% of ethanol volume
Total Nitrogen (as N)	40	36	mg/L-ethanol	Alcohol recovery	97.5	96.4	%
Total Phosphorus (as P)	5	5	mg/L-ethanol				
Urea	0.006	0.006	kg/L-ethanol				
Energy	14.4	21.6	GWh				

Table 6. Emission coefficients in the cane cultivation phase.

Particulars		**Emissions**	**References**
Urea- fertilizer production		5.61 kg CO_2 eq/kg	[18]
Fertilizer application	N_2O	9.83 g/kg-Urea	[19]
	NH_3	170 g/kg-Urea	
	CO_2	733 g/kg-Urea	
Herbicides production		25.3 kg CO_2eq/kg	[20]
N_2O from filter cake application		0.071 kg CO_2eq/kg	[21]
Cane trash burning & decomposition		0.097 kg CO_2eq/kg and 0.018 kg CO_2eq/kg	[21]
Human labour use		5.59 kgCO_2eq/man-day	[21]

Ethanol conversion

After the expansion of both ethanol plants, the production has increased to 8,000 m^3 (Metehara) and 12,000 m^3 (Fincha) during the period of 2016/17. Chemicals were added into the four yeast propagation vessels with 8-12 hours of retention time. The fermentation process took 8 hrs. on average and chemicals were added to adjust the pH levels and to settle down the impurities before going to the filtration section. The Table 5 below lists the input and outputs materials/chemicals measured in the ethanol plants [16-17].

2.6 Impact assessment

This phase of life cycle assessment aimed to evaluate the significance of potential environmental impacts based on the life cycle inventory flow results described in previous section. The ReCiPe life cycle impact assessment model was used; both midpoint and end-point categories were applied for the calculation of environmental impact assessment. Basically, the study is focused on in environmental impacts of global warming, photochemical oxidation formation, terrestrial acidification, marine eutrophication, terrestrial ecotoxicity, land use, resources depletion and ozone layer depletion.

The emission coefficients used to determine the impact burdens related to the cane cultivation activities (presented in Table 2) are obtained from literature and presented in Table 6 below.

Tractors are used to transport sugarcane from the field to the sugar mill as well as filter cake from the milling plant to field. Transportation distance of cane from sugarcane farm to the sugar mill was taken as 15 km on average. The annual amount of diesel used for these purposes in 2016-2017 is presented in Tables 3.A and 3.B above. The emissions coefficients for transportation are listed in Table 7 below.

Table 7. Emission coefficient from transportation of diesel fuel [22].

Emission gases	**Emission coefficient**	**Units**
N_2O	0.087	g/kg fuel
CO_2	3.14	kg/kg fuel
NH_3	0.065	g/kg fuel
NO_X	12.96	g/kg fuel
CO	3.33	g/kg fuel
NMVOC	0.7	g/kg fuel
SO_X	0.016	g/kg fuel

Materials/chemicals and energy (electricity) required for sugar production processes are provided in Table 4. The sugar mill used bagasse as the main energy input for these processes. The emissions coefficients from burning of bagasse and chemicals used that are extracted from literature are presented in Table 8 below.

Table 8. Emission coefficient of bagasse and chemicals in milling process.

Emission factors for bagasse boilers (uncontrolled) [22]		**Used chemicals emission coefficient**	**Reference** [21, 24])
CO	44.64 kg/MWh	Lime	0.5 kg/CO2 eq/kg
NO_X	2.68 kg/MWh	NaOH	501.04 gCO2 eq/kg
SO_X	0.33 kg/MWh	Sulphuric acid	216.2 gCO2 eq/kg
Bagasse combustion	0.025 kgCO_2 eq/kg		

The environmental impacts associated with inputs for ethanol production (given in Table 5) are calculated using the emission coefficients presented in Table 9.

The applicable data from inventory analysis were used for impact assessment while some of background data for materials and energy production were taken from the ecoinvent database based on the countries where they are imported from.

Table 9. Emission coefficients in ethanol production.

Emission factor from Light Fuel Oil Uncontrolled [25]		**Chemicals** [21]	
CH_4	3 kg/TJ	Yeast	0.49 kg CO_2eq/kg
N_2O	0.6 kg/TJ	Urea	1.85 kg CO_2eq/kg
NOX	200 kg/TJ	$MgSO_4$	0.3 kg CO_2eq/kg
NMVOC	5 kg/TJ		
CO	15 kg/TJ		
CO_2	73300 kg/TJ		

3. Results and Discussion

3.1 Midpoint level

The inventory data used for analyzing the impact categories had been collected from the two sugar factories (Fincha and Metehara) during the period 2016 to 2017. In this result, the system boundary was classified into 3 main stages – cultivation, sugarcane milling and ethanol production; intermediate transportation between the above stages was also included. Summary of results are presented in Table 10 below. As the results for both sugar factories were quite similar, they are represented together as simple average values in Table 10.

It can be seen from Table 10 that over the complete life cycle of ethanol production, cultivation stage is the largestcontributor to climate change. It was estimated to be 821 kgCO_2 eq, which is representing 54.5% of the total climate change potential. The main contributor for this impact was production of urea fertilizer and herbicides followed by cane trash burning and decomposition. The high amount of energy consumed in the ethanol plant was another major contributor to this impact at 572 kgCO_2 eq. In the milling process, the burdens resulting from the burning of bagasse were allocated to sugar and molasses. For that reason, burning of bagasse contribute less value for global warming which is 4%. However, the burdens from the use of chemicals were only allocated to the sugar production process. The activities in the ethanol production stage contributed a total 40% towards global warming from both Metehara and Fincha factories. Transportation also contributed to 1.5% on average.

Table 10 shows that ethanol plant is the largest contributor to marine eutrophication at 2.76 kg N eq (92.3%). This was mainly caused by the emissions of gases from the burning of light oil fuel used to provide energy in the ethanol plant and the discharge of waste vinasses into the river. The remaining contribution was from fertilizer production, burning of fuel by transportation and bagasse combustion.

For over life cycle of 1000 L-ethanol production the terrestrial acidification impact value was 79 kg SO_2 eq. From Figure 2, it can be observed that ethanol plant has a great contribution of 99% for this impact. The reason for this impact was untreated discharge of vinasse waste and consumption of high amount of fuel for the plant. Then the burden was followed by fertilizer production, and burning, fertilizer application (7.4%), bagasse burning, and fuel used for transportation contribute for acidification impacts were 0.43 and 0.05 kg SO_2 eq respectively.

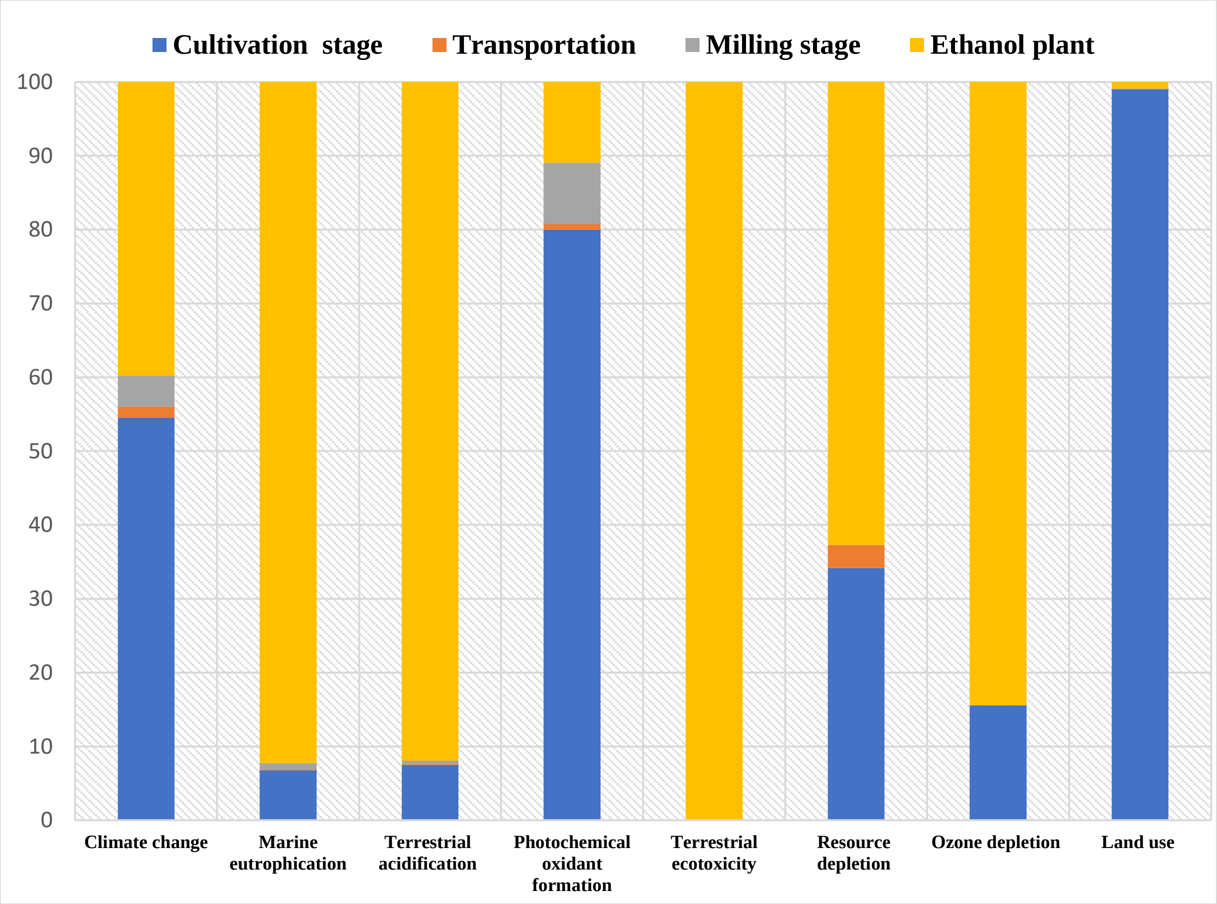

Figure 2. Impact contribution (in %) of 1000 liters of Ethanol along its life cycle stages.

Table 10. Activities stages with midpoint impact categories results per 1000 liters of ethanol.

Impact categories	**Mid-point**				
	Unit	Cultivation stage	Transportation	Milling stage	Ethanol plant
Ozone depletion	kg CFC-11 eq	3.3E-07	-	-	2E-06
Photochemical oxidant	kg NMVOC eq	10.7	0.1	1.11	1.46
Climate change	kgCO_2 eq	821	22.7	86.05	572
Terrestrial acidification	kg SO_2 eq	6	0.05	0.432	72.6
Terrestrial ecotoxicity	kg 1,4-DB eq	0.007	3.3E-06	-	9.6
Land use	m^2a	1E+7	-	8,200	92,500
Marine eutrophication	kg N eq	0.2	0.0037	0.025	2.76
Resource depletion	kg oil eq	85.4	7.8	-	157

Table 10 shows that 10.7 kg NMVOC eq (80%) of photochemical oxidants came from cultivation stage, due to by high amount of energy consumption for urea production and emission of gases (NO_X, SO_X and CO) released during the of trash burning. Ethanol production and milling stage follow with 10 and 8% respectively. Transportation has the lowest contributor for photochemical oxidant impacts (0.7%). The other impact category considered in the study was resource depletion; the total burden was 250 kg oil eq, to produce 1000 L-ethanol. All activities including cultivation, diesel use, chemicals, and light fuel oil use in the ethanol production stage were considered. The main resource depleted in average from both sugar factories was 62% (157 kg oil eq) in ethanol stage because of high fuel consumption in distillation process. This was followed by cultivation at around 34% (85 kg oil eq). Transportation has also 3% contribution for this impact category.

In the case of terrestrial ecotoxicity, the total impact through the whole life cycle of ethanol production was 9.61 kg 1,4-DB eq. The main contributor was vinasses discharge and light fuel oil for electricity in ethanol production stage, 99%, and followed by cultivation stage due to the use of high amount of fuel energy for urea fertilizer production 0.007 kg 1,4-DB eq (0.07%). On the other hand, the terrestrial ecotoxicity impact from transportation was negligible. From the figure above, land use was highly dominated by the cultivation stage (99%); rest having a very small contribution.

3.2 Endpoint level

Human health, ecosystem quality and resource scarcity are the three endpoint indicators in the ReCiPe2016 methodology. Human health is expressed in units of DALYs (disability adjusted life years), the ecosystem quality is measured as the local species loss integrated over time or species year and resource scarcity as dollars ($) representing the extra costs involved for future mineral and fossil resource extraction. The final endpoint results are represented in Table 11 below.

Table 11. Activities stages with endpoint impact categories results per 1000 liters of ethanol.

Activities	**Human Health (DALY)**	**Ecosystem damage (Species. Yr)**	**Resources ($)**
Cultivation stage	1.4E-06	8.97E-02	39.3
Transportation	-	8.75E-08	3.6
Milling stage	4.34E-08	1.70E-04	-
Ethanol production	1.9 E-07	1.92E-03	72
Total	1.62E-06	9.2E-02	115

The impact categories contributing to human health were climate change, photochemical oxidant formation and ozone depletion. Table 11 shows that most of the contribution to human health is from the cultivation stage 1.4E-06 DALY (85.6%), followed by ethanol plant 1.9E-07 DALY (11.7%) and sugar milling contributing a smaller portion 4.34E-08 (2.7%). Transportation had an insignificant contribution to human health. Damage to ecosystems is contributed by climate change, terrestrial acidification, terrestrial ecotoxicity, land use and photochemical oxidant formation. The highest damage on ecosystem quality comes from the cultivation stage which contributes 96% due to the land use impact which has high damage to the ecosystem quality followed by ethanol production 1.92E-03 (2%). The damage to resources was mainly from the ethanol stage 72 $ (63%) due to the used of light fuel oil for distillation and dehydration. The second largest contribution was from the cultivation stage 39.2 $ (34%) due to the high amount of energy used to produce fertilizer. Transportation contributes 6.5%. The source of energy for the milling process was from combustion of bagasse produced during the milling stage. The damage to resources in this stage was thus not considered since no external fossil resources were used.

3. Conclusion and Recommendation

This study focused on the environmental performance of typical ethanol production from molasses in Ethiopia. The impacts categories that were considered for in this study included: global warming, photochemical oxidation formation, terrestrial acidification, marine eutrophication, terrestrial ecotoxicity, land use, resources depletion and ozone layer depletion. Based on a functional unit of producing 1000 L-ethanol, the overall results were found as: climate change of 1,506 kgCO_2 eq, photochemical oxidation formation of 13.4 kg NMVOC, terrestrial acidification of 79 kg SO_2 eq, marine eutrophication of 3 kg N eq, terrestrial ecotoxicity of 9.6 kg 1,4-DB eq, land use of 1.02E+07 m^2a, resources depletion of 250 kg oil eq and ozone layer depletion of 2.33E-06 kg CFC -11 eq. On the other hand, the result at endpoint level was: human health 1.652 E-06 DALY, ecosystem damage 9.2E-02 Species. Yr and resource depletion has 115 $.

The main contributors to climate change were the production of fertilizer and herbicides, cane trash burning, and decomposition and application of fertilizer and filter cake recorded from cultivation stage. On the other hand, the use of high amount of fuel for ethanol plant and diesel for transportation case had additional contribution to climate change.

The main cause of terrestrial acidification, photochemical oxidant formation, terrestrial ecotoxicity, and marine eutrophication were the production of urea, fertilizer application as well burning of cane in cultivation stage. In addition to those activities, burning of fuel for transportation and energy use for ethanol plant with associated of a discharge wastes vinasses into river and soil had a great contribution.

The results lead us to the recommendations to prevent/ reduce the burdens (i) prevent cane trash open burning in the field by changing the mechanism of harvesting from burning to the use of machines such as harvesters, (ii) change from the use of chemical fertilizers to organic fertilizers like compost (filter cake with vinasses) or animal manure rather than discharging these in the landfill and water bodies; this can lead to the decrease in global warming impact in cultivation stage from 821 to 714.5 kgCO_2 eq and the total percentage contribution in ethanol stage for terrestrial acidification and marine eutrophication will decreased by 5% and 49% respectively (iii) using different kind of fertilizers (mixed urea with ammonium nitrate and diammonium phosphate) can reduce the global warming, photochemical oxidant formation and resource depletion impacts respectively by 11%, 2% and 10%. (iv) Up to 45% of burning of cane during harvesting can be considered an important waste of energy. This potential energy could reduce the dependence of fuel in ethanol plant station and thus contribute in a small way to a reduce environmental impacts. For high energy use activities, it may be preferable to look more towards the use of renewable resources. Also, the wastes should be treated before disposal for the sake of protecting the environment; the government should give a serious attention and control it.

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