Research on Engineering Structures & Materials

journal homepage: http://www.jresm.org

MIM Research Group

Research Article

Effect of asphalt pavement construction on the environment of Ethiopia

Badrinarayan Rath

Civil Engineering Department, Wollega University, Nekemte, Ethiopia.

Article Info

Article history:
Received 10 Oct 2021
Revised 06 Feb 2022
Accepted 22 Feb 2022

Keywords:

Asphalt Pavement; Environmental Impact; Life Cycle Impact Assessment; Biodiesel

Abstract

Nowadays road construction is rapidly increasing on-demand to meet several medium and long terms development programs. A huge amount of natural resources, types of machinery and fuels are used in road construction. Using material resources and fuel an efficient manner, reducing in emission of greenhouse gases and controlling various impacts on the environment are important tasks in the road construction industry. In the present research, several environmental impacts related to the construction of asphalt paved highways in Ethiopia have been determined using the Life Cycle Assessment Approach for common pavement materials and construction activities. A deep focus has been given towards the extraction and processing of sand and gravel for preparation of base and sub-base; transportation of these input raw materials; consumption of fuels by various road construction machinery; direct or indirect emissions of carbon dioxide and other pollutants to atmosphere etc. Various suitable methods have been used to calculate the impacts of raw materials, fuel and machinery on various categories such as global warming potential, ozone depletion potential, terrestrial acidification potential, freshwater eutrophication, freshwater ecotoxicity etc. From the investigation, it has been suggested to use recycled materials for substituting gravel as base or sub-base materials and biodiesel for substituting diesel in the transportation trucks and dumpers. These types of new recycled materials may greatly help in assisting the evaluation of sustainable pavement construction. The present case study may help for potential changes in asphalt pavement construction to improve environmental sustainability.

1. Introduction

Roads are the arteries of the country, deeply associated with its socio-economic development. It is the only infrastructure, by which society can access the resources, consumer goods and various services easily at a low cost. As the population of the world is increasing, the demand for road infrastructure is increasing in that proportion. It is found that a total of forty-three million km length of paved road has been spread throughout the world till 2010 and has targeted to construct additional fourteen million km up to 2030 [1]. Any construction (particularly road construction) inside the country causes many environmental impacts such as consumption of natural resources, deforestation, disturbances of natural habitats, a huge amount of greenhouse gas emission, the transformation of land etc [2]. Cement and aggregates are the main ingredients are used for the preparation of concrete by consuming a huge amount of natural resources. Due to the continuous consumption of a natural resource, our environment and ecosystem are

*Corresponding author: rath_rcpit@rediffmail.com
[a] orcid.org/0000-0001-9675-9684
DOI: http://dx.doi.org/10.17515/resm2022.352ma1010

badly affected. Hence geopolymer concrete can be suggested for road construction instead of cement concrete.

In Ethiopia, National highways and expressways have been constructed radiating from its capital city to several regional state capitals in all directions. Ethiopian Roads Authority has set a target to complete the expansion of roads up to two lakhs kilometres at the end of the current year 2021. All these proposed roads are asphalt roads and the life cycle assessment approach is best accomplished for quantifying the environmental impact of those road pavements. The Ethiopian roads can be classified based on three categories as shown in Table 1. They are Technical Classification, Functional Classification and Political Classification. The detailed road classification of Ethiopia is given below. During the most recent periods, various studies have been done on the environmental impact of road infrastructure. Among those studies, it has been focused on the environmental impact of asphalt pavement [3], it has been studied to compare the environmental impact of different pavements [4, 5], it has been explanted about the traffic fuel consumption on a different surface of the layers during the use phase or on maintenance strategies [6] and it has been studied about a review on existing of life cycle assessment [7]. Several researchers have studied the life cycle of road pavement and divided it into five categories [8, 9]. They are extraction of raw materials, construction of road, using of road and end of its life [10]. Now a days people are focusing on the exploration of various sustainable options for the construction of asphalt pavement such as its reusing, extending its lifetime [11], using recyclable materials in road construction [12], reducing of friction in between pavement and wheels of the vehicle [13]. Now a days reclaimed asphalt pavement is considered as standard asphalt pavement practice. In this process, the combined materials of asphalt and aggregates collected from old damaged asphalt road are feeding to the hot recycling of asphalt paving mixtures. In the early days recycling of pavement, process had been practiced. This type of sustainable effort was conducted in Nevada and Texas during 1974, by recovering and reusing the old asphalt paving materials [14]. The life of pavement can be extended by using a geosynthetic insulation layer with low heat conductivity [15]. Now a days various recyclable materials are used in road construction. It was found that replacing recycled polymers with coarse aggregate up to 15% in road construction increased its strength and performance with attaining sustainability and reducing the negative effect on the environment [16]. Also, it was noticed that various rejuvenators such as waste engine oil, waste cooking oil virgin olive oil can restore the aged asphalt binder to a penetration grade of 60/70 [17]. The friction resistance can be reduced by improving the flexible pavements using above rejuvenators in asphalt. As a result, vehicle energy, as well as greenhouse gas emission, will be reduced significantly. To reduce the friction and improve the asphalt mix stability performance HDPE plastic seeds can be added to asphalt at 5.5% as optimum value [18]. Due to the addition of HDPE plastic seeds into oil asphalt, the penetration value reaches 60/70. However, people are focusing on construction and maintenance phases. Various activities such as raw material extraction and its transportation, production of materials, application of pavement materials is often incorporating in the construction phase. Many studies such as Pavement Embodied Carbon Tool (PECT), Intergovernmental Panel on Climate Change (IPCC), Functional Unit (FU) have highlighted various difficulties for obtaining various data during the life cycle assessment of roads [19].

A huge amount of raw materials such as gravel, sand, bitumen, cement and water is required for the construction of road pavements. To optimize the road pavement design, several types of impacts such as environmental, economic and social on the materials should be quantified and monitored. At present condition, no such type of protocol has been applied in Ethiopia. This type of quantification is required to develop a holistic life cycle assessment model on design and technology of construction, maintenance and rehabilitation. Hence the first step for the development of such a holistic life cycle assessment model is an analysis of life cycle inventories. The life cycle assessment process consists of tracking resources, energy, input materials, outputs of waste, coproducts etc to provide a proper indicator to the system against various environmental impacts [20]. Moreover, due to local construction techniques and context-dependent aspects, the road section has been analyzed for the designed traffic load and its life span. The production of various road materials highly influences the lifecycle environmental impact [21]. Particularly production of bitumen influences asphalt pavement and the production of cement influences concrete pavement [22]. Besides the production of road materials, road maintenance also plays a significant role in the lifecycle environmental impact [23]. From the literature review, it is found that near about one-third of life cycle environmental impact are caused by the various operations for maintenance such as asphalt overlay, reconstruction, thin hot-mix asphalt (HMA) overlay, chip seal, crack seal and cold in-place recycling (CIR) with foamed asphalt etc. Traffic fuel consumption is another environmental impact that is much higher than the environmental impact due to the production of road construction material and road maintenance [13]. The consumption of energy from construction, maintenance and operation of the road is only 9.9% whereas the consumption of energy due to traffic is near about 11.8% [21]. Also, several authors have recommended that for the analysis of traffic fuel consumption, the texture of road surface should be included [6] [24], [25]. If one compares to the environmental impacts between concrete pavement and asphalt pavement, it can be concluded that global warming potential and human health impacts are more contributed by construction and maintenance of concrete pavement while acidification, photochemical smog and eutrophication are more contributed by construction and maintenance of asphalt pavement [7]. Besides the lifecycle environmental impact, lifecycle costing is also increasing in the transportation sector. Various countries like the USA, Europe and Canada are using lifecycle cost at a state-of-the-practice [26]. Comparing concrete pavement and asphalt pavement it is found that concrete pavement is more expensive but suitable for a higher traffic intensity. Because concrete pavement requires lower maintenance frequencies and a less amount of thickness of concrete is required for higher traffic intensities [27].

The environmental licensing monitors the various socio-environmental impacts, which depends on the elaboration of environmental impact studies such as climate change, ozone depletion, ecotoxicity, acidification, Eutrophication etc. [28]. These studies always require several types of impacts caused by the activity, which include an order of magnitude estimation of indirect and direct impacts. But the life cycle approach is not followed by these studies, whether the road built will reduce the habit disruption and deforestation or not. In other words, the various impacts related to road construction are not assessed. Thus, the objective of this study is to determine the environmental impacts associated with the construction of the road in Ethiopia using the life cycle assessment method.

In the present research, a deep level study has been done by the two road projects of Ethiopia (Addis Ababa- Ambo and Addis Ababa-Adama) and found that a huge amount of natural resources has been deployed for the construction of those road pavements. Various types of environmental impacts have been quantified. It is found that the major reason for the pollution of environment (i.e. air, water and soil) is due to the consumption of huge amount petroleum fuel on various activities of road construction such as mining of hills for natural aggregates, transportation of the materials from mines to crushing centre and crushing centre to the construction site, operation of various types of machinery, refining of petroleum products for getting bitumen etc. To reduce this environmental pollution due to a huge amount of fuel consumption, using biodiesel is suggested in vehicles and types of machinery used for road construction. A comparison has been shown between using of petroleum fuel and biodiesel in various types of construction machinery on various environmental impacts.

Table 1. Classification of Ethiopian roads [29]

<table>
<tr><th colspan="4">Technical Classification</th><th colspan="5">Functional Classification</th><th>Political Classification</th></tr>
<tr><th>DS</th><th>Traffic (ADT)</th><th>Width (m)</th><th>Type of Surface</th><th colspan="5"></th><th>Ownership</th></tr>
<tr><td>DS-1</td><td>10K-15K</td><td>7.2</td><td rowspan="4">Asphalt</td><td></td><td></td><td></td><td></td><td rowspan="5">Trunk</td><td rowspan="5">ERA (Federal Roads)</td></tr>
<tr><td>DS-2</td><td>5K-10K</td><td>7.2</td><td></td><td></td><td></td><td rowspan="5">Link</td></tr>
<tr><td>DS-3</td><td>1K-5K</td><td>7.0</td><td></td><td rowspan="6">Collector</td><td rowspan="5">Main Access</td></tr>
<tr><td>DS-4</td><td>200-1K</td><td>6.7</td><td></td></tr>
<tr><td>DS-5</td><td>100-200</td><td>7.0</td><td rowspan="4">Gravel</td><td rowspan="6">Feeder</td></tr>
<tr><td>DS-6</td><td>50-100</td><td>6.0</td><td></td><td rowspan="3">RRAs (Regional Roads)</td></tr>
<tr><td>DS-7</td><td>30-75</td><td>4.0</td><td></td><td></td></tr>
<tr><td>DS-8</td><td>25-50</td><td>4.0</td><td></td><td></td><td></td></tr>
<tr><td>DS-9</td><td>0-25</td><td>4.0</td><td rowspan="2">Earth</td><td></td><td></td><td></td><td></td><td rowspan="2">Woreda Rural Road Office</td></tr>
<tr><td>DS-10</td><td>0-15</td><td>3.3</td><td></td><td></td><td></td><td></td></tr>
</table>

2. Research Significance

The pavement construction process of the country passes through several phases such as the production of raw materials, transportation of raw materials, construction of pavement, use and maintenance of pavement, and its end life. All these processes possess a unique burden on the local environment [30]. Hence evaluation of the environmental impact of the country's pavement by using lifecycle assessment is the best solution for getting a future warning to society and the construction industry. Lifecycle assessment can assess a product from cradle to grave, explore everything from each and every supply chain process to recycling or disposal after reaching of product at its ultimate end life. In the present condition, no lifecycle data on environmental impact are available in the ordinance of the Ethiopian Road Authority (ERA). The aim of this study is to evaluate various environmental impacts which are associated with the construction of asphalt pavement in Ethiopia by using a life cycle assessment approach.

The life cycle assessment process includes the various construction activities such as extraction of gravel, sand and asphalt and their process; transportation of these materials to the construction site; use and operations of various types of machinery; emissions of greenhouse gases directly or indirectly from materials, transportations and types of machinery fuel. The required input data have been collected from two road projects of Ethiopia. Various impacts are calculated by the ReCiPe method for each category and verified by a suitable alternate method. After analysis of environmental impact, an alternative scenario has been proposed to replace petroleum diesel with biodiesel in diesel-operated machinery and transportation trucks. The innovative part of the present research is the finding of different factors which affect the local environment badly during the road construction process of Ethiopia and finding out the solution for reducing the environmental pollution. A limited amount of research has been found on how the local environment has been badly affected due to the various construction process in Ethiopia. For this reason, two case studies (Addis Ababa-Ambo and Addis Ababa-Adama highway) on the asphalt road project have been deeply studied. It is found that the air is polluting due to the emission of greenhouse gasses from various types of construction machinery, vehicles used for transportation of construction materials, hot mix plant, crushers, petroleum refineries plant etc, whereas the local watersheds and soils are polluted from petroleum refineries plant, washing of various types of construction machinery and materials. Since the major factor of pollution is the emission of greenhouse gasses, biodiesel is suggested to use in various types of machinery and vehicles for the construction process. It is also found that by using of biodiesel in construction machinery then air pollution can be reduced more than 50%.

3. Methodology

3.1. Method for Life Cycle Assessment

The Life Cycle Assessment (LCA) is divided into four different parts. They are the definition of aim and scope, life cycle inventory, assessment of impact, interpretation of results [31]. The present study aims to determine the environmental impacts of the construction of flexible asphalt pavement in Ethiopia. The observation sample has been taken as 1 km of the two-lane highway for a total road width of 7.3 m. The following activities have been encompassed in the present system. They are extraction or production of road construction materials such as sand, gravel and asphalt; transportation of those road construction materials to and within the construction site; production of asphalt from hot mix concrete plant near to the site; preparation of land for pavement construction by excavation and compaction and application of pavement materials. Energy, road construction materials and fuels needed for all activities are taken as input. Emission of all types of greenhouse gases to the atmosphere directly or indirectly during the above activities is considered as output. The direct emission may be from the construction of the pavement and the indirect emissions are those emissions from the different processes before pavement construction such as raw material extraction, asphalt production, during transportation of raw materials to the site etc. Two factors such as intensity of usage and frequency of maintenance may vary on the lifetime of the road. But the frequency of maintenance may be in between 10 to 15 years. The financial expenses during the different lifecycle stages are considered within the Life Cycle Cost approach. They are investment costs such as expensive for materials, labour and indirect costs for initial construction, maintenance, cleaning, energy cost at the time of use phase and demolition cost and treatment of waste at the time of the end-of-life stage. The life cycle financial cost is the sum of all expenditure occurring during the period of the life cycle of the road infrastructure. This research is following an attributional approach, to determine the environmental impacts that stem from the flow of energy to and from the system boundary. All activities are linked from activity producing waste to the process of waste treatment by the allocation method, which is used at the point of substitution. The whole system considered in the study is shown in Figure 1. Since all the transportation trucks in Ethiopia are using diesel as a fuel, this research also considered the environmental impacts when biodiesel will be filled in the truck instead of petro-diesel for transportation of raw materials to the construction site.

3.2. Life-Cycle Inventory

The amount of materials required for road pavement construction and using of inventories for extraction or production of those materials are described in this section. It also consists of the consumption of fuel and greenhouse gas emissions at the time of freight transportation and machinery operation.

3.2.1. Materials Used in Ethiopian Roads

The width of the road and the depth of the layers is directly related to the environmental impacts. In most parts of Ethiopia, the width of the road is 7.2 m. Most of the pavement in this country possesses the following layers. They are (i) Natural Subgrade, (ii) Compacted Subgrade, (iii) Sub Base Course, (iv) Base Course, (v) Binder Course (vi) Finishing Coat. Since the surface coat is thin layers, they are calculated based on the area of application. The construction depth for each layer and the ratio between thick layer density to the utilized area for thin layers are showing in Table 3. There is no specific rule for road construction products in Ethiopia, hence it was not required to follow any product category rule. The technical specification for various road construction material such as gravel, binders, asphalt, sand etc has been followed as per Ethiopian standards [32].

Table 2. Depth of pavement layer and quantity of materials applied in 1 km road

Layers	Depth (m)	Ratio of Application	Quantity (Metric Ton)
Sub-Base Course	0.35	2150 kg/m^3	5423
Base Course	0.15	2150 kg/m^3	2324
Binder Course	0.05	2400kg/m^3	864
Finishing Coat	0.04	2200 kg/m^3	634

Table 3. Pavement layer composition (kg)

Layers	Gravel	Sand	Asphalt
Sub-Base Course	1	0	0
Base Course	1	0	0
Binder Course	0.81	0.25	0.05
Finishing Coat	0	0.11	0.07

Table 4. Total quantity of materials for the construction of 1 km road with 7.2 m width

Particulars	Quantity	Unit
Gravel	8500	Metric Ton
Sand	300	Metric Ton
Asphalt	100	Metric Ton
Material transportation to the construction site	695000	Tkm
Material transportation within the construction site	190000	Tkm
Excavator (Poclain or JCB)	4307	M^3
Diesel used in construction machine and hot mix plant	7200	Litre
Diesel operating machinaries	15	Operating hours
Electricity used for crushing of stones	2000	kwh

Both the sub-base and base course are filled by gravel only. Both binder course and finishing coat are assumed as filled by asphalt. The filler in the binder course is sand. Due to the thin section of the binder course and finishing coat, the amount of materials has been calculated on the basis of surface area. Two different bitumen mixes have been prepared for both binder course and finishing coat depending upon the percentage of aggregate materials (i.e sand and gravel). The Binder course has larger aggregate materials as compared to the finishing coat.

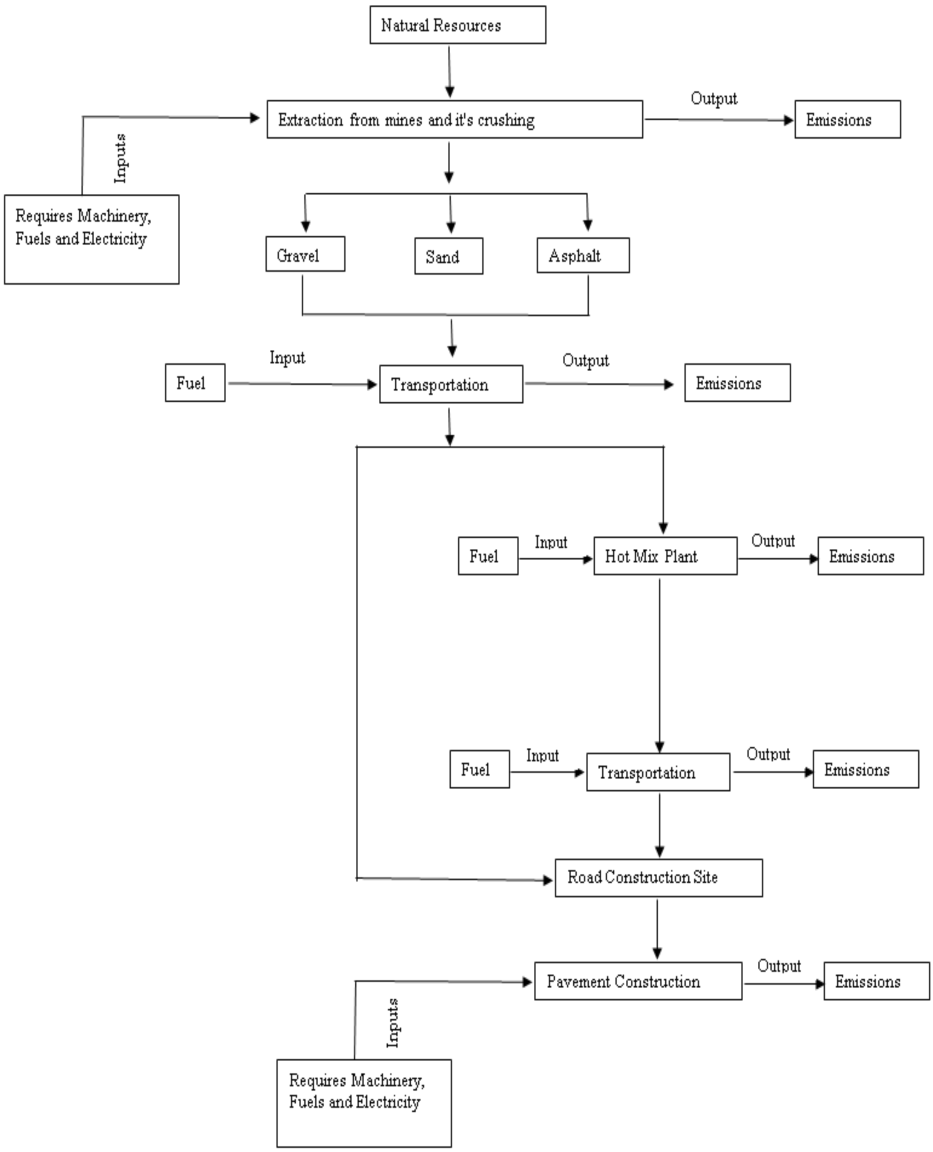

Fig. 1 System diagram for energy consumption and green house gas emission during pavement construction

3.2.2. Classification of Road Construction Materials for Extraction and Production

Based on the total quantity of materials of each layer and the composition of each layer, the quantities of gravel, sand and asphalt required for the construction of pavement for 1 km length and 7.2 m width is possible. The detailed quantity of materials for above is shown in Table 4 for the corresponding depth shown in Table 2. In Table 2 the depth of different layers has been taken according to Ethiopian Building Code. The density of local materials required for each layer has been determined in the laboratory. The width of the road is taken as 7.2 m. The mass of materials for each layer has been determined by the multiplication of the volume of each layer with the corresponding density of materials. The required quantity of materials may vary depending upon the width of the lane and the depth of the layers.

Three extraction and production types of materials (Sand, Gravel and Asphalt) are described here. The sands are extracted from the river bed. The process includes dredging of slurry (i.e. mixture of sand, water, silt and clay) from the river, washing of sand to separate clay and silt and transportation of the separated sand to the site. This process considers the energy for loading on the trucks but does not consider the separation of sand from silt and clay. All equipment is considered as diesel running equipment. The gravels are collected from an open granite quarry. The extraction process includes drilling and blasting of stones in open pits, transportation of mined big stone blocks to crushers, crushing of big stone blocks into gravels of different sizes by electric operated crusher, loading and unloading of crushed stones into delivery trucks. The production process of asphalt was developed in such a way that the end products obtained with some specific impacts because it should be followed some specific allocation rules to confirm the impacts for asphalt product were correctly determined. The whole extraction process of asphalt passes through the various process such as the construction of refinery infrastructure, storage of crude oil in refinery ground, feeding of crude oil into the refinery, supplying of freshwater from nature for refinery process, wastewater treatment process exhausted from refinery plant and use of energy.

3.2.3. Detailed Process of Transportation of Materials

The distance for transportation of road construction material to the construction site or within the construction site depends upon the geographical locations and ease of connectivity of road construction projects with other service roads. In this study, the transportation distance has been recorded as the average distance of two road construction projects of Ethiopia. The detailed distance for transportation of different materials is shown in Table 5 has been recovered from Final Project Report, Ethiopian Road Authority 2019 [33]. The total quantity of materials for 1 km road construction to the construction site or within the construction site (Table 4) is calculated based on total transportation distance (Table 5) and quantity of composition materials used in each pavement layer (Table 3). It is assumed that the transportation of all materials is carried to the construction site or with in construction site by trucks of a capacity of 23 metric tons. The inventory for transportation of material includes all activities such as production maintenance of the truck, production of diesel, construction and maintenance of road. A small modification has been done such as low sulfur diesel production in Ethiopia has suggested instead of petroleum diesel.

3.2.4. Various Machinery Operation

For base preparation and soil excavation, excavators like poclain and JCB are used. Various types of machinery are used for each layer of pavement as follows. For sub-base course sheep foot compactor, for base course sheep foot compactor followed by a smooth wheel roller, for binder course asphalt spray truck, paver, pneumatic roller and for finishing coat paver, smooth wheel roller have been used. Electricity has used for rotating the mixture drum, running the pumps, compressors, fans, elevators, driving the belt etc while diesel has used for the operation of the hot mix plant for heating the mixtures. The total operating hours, volume for excavation, consumptions of electricity and diesel are summarized in Table 6. From the Ecoinvent database [34] machinery operation inventories are obtained. The capacity of all machinery is assumed as above 75kW and high load factor, operated by diesel and the mode of operation has considered as operating hours. It is based on calculations performed by US EPA's Motor Vehicle Emissions Simulator (MOVES) [35]. The inventory for the excavator has based on excavated volume.

The hot mix plant operation has been divided into two categories. The first one is the heating process running on diesel and the second one is building machine running on electricity. All inventories are used for local geography with incorporating necessity modification to Ethiopian electricity production mix [36].

Table 5. Transportation distance to the construction site or within construction site for present research

Materials	From	To	Total Distance (km)
Sand	River bed	Hot mix plant/Storage site	150
	Storage site	Application on pavement	10
Gravel	Mines	Hotmix Plant/ Storage site	100
	Storage site	Application on pavement	10
Asphalt	Petroleum Refinery	Hotmix plant	600
Hot mixed bituminous mixture	Hotmix plant	Application on pavement	10

3.2.5. Production of Bio-Diesel and its use in Transportation Trucks

In the present research, an alternative scenario has been suggested that to use biodiesel instead of petroleum diesel in transportation trucks as a fuel [37]. The biodiesel can be formed from various African oil bean seeds [38]. It will give a positive impact on the environment and cost during transportation of materials to the construction site. For the production of biodiesel and transport trucks running on this biodiesel, a separate inventory is required.

The African oil bean seeds are consuming at a limited amount by local people as a vegetable and can be categorized as an underutilized crop. Though this crop has a good yield in present condition, a few numbers of local farmers are cultivating these types of crops. Due to lower demand in the market, farmers are not getting a good sum. If these oil bean seeds will be used for extraction of edible oil and made the conversion of oil to other product, then its value will be added and a higher financial turnover can be yield.

3.2.6. Life Cycle Impact Assessment

To determine the impacts on various categories such as Global Warming Potential, Ozone Depletion Potential, Terrestrial Acidification Potential, Freshwater Eutrophication Potential and Freshwater Ecotoxicity Potential. To calculate the impacts, two types of approaches have followed. The first one is ReCiPe 2016 [39] and the second one is different methods for evaluating impact from the ILCD handbook. For the Global Warming Potential category, the IPCC 2013 method [40], for Ozone Depletion Potential and Terrestrial Acidification Potential category the CML 2001 method [41], for Freshwater Eutrophication Potential category USEtox v1.0 method and Freshwater Ecotoxicity Potential category EDIP 2003 method [42] has been used. To evaluate the impacts of each system of production, open Life Cycle Assessment software version 1.10.2 has been used [43].

Table 6. Specifications for various machineries operated in pavement construction

Layer	Type of Machinery	Specification
Excavation	Excavator (Poclain or JCB)	Based on the excavated volume
Sub Base Course	Sheep-foot Compactor	No of passing per lane: 8 Power of Compacter: 100 kW Avg. speed of Compactor: 5.5km/h Compactor width: 2.1m
Base Course	Sheep-foot Compactor	No of passing per lane: 6 Power of Compacter: 100 kW Avg. speed of Compactor: 5.5km/h Compactor width: 2.1 m
	Smooth Wheeled Roller	No of passing per lane: 10 Power of Compacter: 100 kW Avg. speed of Compactor: 5.5 km/h Compactor width: 2.1m
Binder Course	Asphalt Spray Truck	Power: 205 kW Average Speed: 4 km/h
	Paver	No of passing per lane: 2 Power: 200 kW Paver width: 2.5m Avg. Speed: 4 km/h
	Pneumatic Roller	No of passing per lane :8 Power: 100 kW Avg. speed: 10 km /h Roller width: 2.1m
Finishing Coat	Paver	No of passing per lane: 2 Power: 195 kW Paver width: 2.5m Avg. Speed: 4 km/h
	Smooth-wheeled Roller	No of passing per lane: 6 Power: 195 kW Paver width: 3m Avg. Speed: 4 km/h
Mixer	Hotmix plant	Plant capacity: 130 t/h Power: 240 kW Fuel Consumption: 7.2 L/t of asphalt mix

4. Results and its Interpretation

Figure 2 and Figure 3 show the impacts on various categories that have been considered in the present research. The impact of each process within the road pavement construction has been shown in Figure 4 and Figure 5 as a percentage contribution and following notations have been given for different processes. The notation for "Sand", "Gravel" and "Asphalt" shows the extraction of these materials; Transport refers to the transportation of all above material; and the word "Machinery" indicates use and operation machinery for the building of the pavement. Notation C1 represents the condition for the present situation i.e. all transport vehicles are fueling by petroleum diesel whereas notation C2 represents the alternative condition i.e. all transport vehicles are fueling by biodiesel.

4.1. Total Impact

The total impact of both conditions i.e. C1 and C2 are analyzed in Table 7. For condition C1, two types of life cycle impact assessment approaches have been implemented. They are ReCiPe and combined methods. For condition C2, only ReCiPe has been used. Figure 2 and Figure 3 are showing the total impact for conditions C1 and C2 by using the ReCiPe method. From Figure 2 and Table 7 it can be seen that the transportation truck fueled by biodiesel (C2) has lower environmental impacts than the transportation truck fueled by petroleum diesel (C1). By comparing two conditions C1 and C2 it has been found that values of C1 are 41.6%, 11.1%, 20%, 50% and 60% more than w.r.t the values of C2 for different types of impacts such as GWP, ODP, TAP, FWEP and FWECP respectively. Again, from Figure 3, it has been found that there is a close relationship between methods used for various categories of life cycle impact assessment except for FWECP. The normalized value was calculated by ReCiPe method and IPCC method for GWP, ReCiPe method and CML method for both ODP and TAP categories, ReCiPe and EDP method for FWEP category. But there is a large difference between ReCiPe and USEtox for the FWECP category.

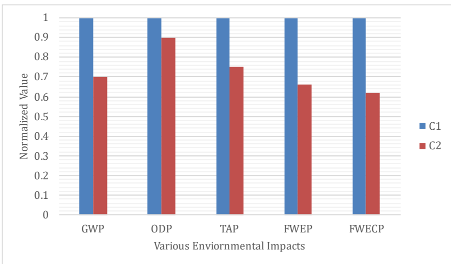

Fig. 2 Total impact for both conditions C1 and C2 calculated by ReCiPe method

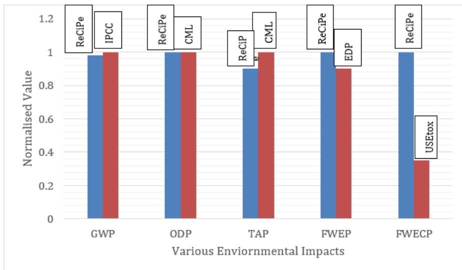

Fig. 3 Comparision between ReCiPe and combined methods for calculation of total impacts

Table 7. Total impacts for conditions C1 and C2 by using life cycle impact assessment approaches

Types of Impact	ReCiPe 2016		Combined Methods	Unit
	C1	C2	C1	
GWP	2.45E+5	1.85E+5	2.48E+5	kg CO_2
ODP	8.5E-2	7.65E-2	8.5E-2	kg CFC
TAP	2.3E+3	1.9E+3	2.53E+3	kg SO_2
FWEP	1.75E+1	1.6E+1	1.61E+1	kg P
FWECP	2.5E+3	1.9E+3	2.53E+3	kg 1,4-DCB

4.2. Role of Each Process to the Total Impact

There is a various process who plays an important role to the impacts for the condition C1 based on the ReCiPe method are gravel, asphalt and transport. The maximum contributions of machinery are near about 15%, while sand has a very negligible contribution to all impacts. Various contributions of materials and process in percentage on total impact by ReCiPe method has shown in Figure 4. It is found that the gravel impacts on TAP at the highest percentage and on ODP at the lowest percentage by both methods. Asphalt contributes near about 50% on ODP as highest and 10% on FWECP as the lowest percentage. The contribution of sand to total impact is very negligible. Machinery contributes at an equal level to all categories impacts ranges in between (10% to 13%).

Transport contributes near about to 52% on GWP as of the highest percentage and 15.5% on TAP as the lowest percentage of contribution. Again, from Figure 5, it can be seen that when biodiesel (C2) is used instead of petroleum diesel (C1) there is an increase in the transportation process for all categories except ODP. The transportation process decreased from 28.7% to 18.4%.

5. Brief Discussions of Results

Based on an interpretation of results impact from the various parameters such as sand, gravel, asphalt, machinery and transportation, a brief discussion with its scientific causes has been quoted after analyzing the results. In this analysis, every process has been a break down into various subprocesses and their impacts resulting from each of them. From the contribution tree of open life cycle analysis software, the contribution of each sub-process to the total impacts has been obtained and discussed briefly as follows.

5.1. Global Warming Potential (GWP)

From Figure 5, one can notice that the Global Warming Potential category has been influenced by mainly the transportation process which is analyzed for conditions C1 and C2 (above 50% contribution). Also, by ReCePi and IPCC method, Global Warming Potential has been influenced by the transportation process showing its contribution percentage as above 50% for condition C1. This highest value is showing due to the emission of carbon dioxide into the atmosphere directly during transportation. The production and utilization of diesel fuel to other machinery are showing 13% and 12% by ReCiPe and IPCC method respectively. Seeing the more contribution of transportation process to Global Warming Potential due to using petroleum diesel in transportation truck and other machinery, biodiesel is used as an alternative fuel. Vegetable oil is the main source of biodiesel for the African country. Though biodiesel is eco-friendly, the transportation process showing higher contribution towards Global Warming Potential. This is due to the transportation of vegetables to the oil mill for grinding and preparation of biodiesel. Near about 70% contribution is giving to Global Warming Potential for transportation of raw materials. Hence it is recommended that more biodiesel plants should be established near the firm land of Ethiopia. Again, it can be seen that the transport category only impacts near about 4.5% caused by the emission of carbon dioxide during transport itself since 95.5% of these emissions of carbon dioxide are non-fossil [44].

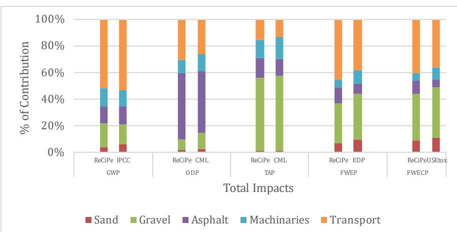

Fig. 4 Contribution of different categories to the total impacts by various methods for condition C1

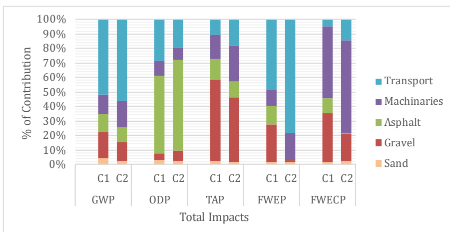

Fig. 5 Contribution of different categories to the total impacts by both conditions C1 and C2

Since the transportation of vegetable seeds to the oil mill and production of fuel has been considered in condition C2, the biodiesel impacts more than petroleum diesel on Global Warming Potential though it has been replaced to the petroleum diesel to a transportation truck. But for the extraction of sand, gravel and asphalt the biodiesel (condition C2) impacts less than petroleum diesel (condition C1). For condition C1, the process of gravel is showing an 18% contribution to Global Warming Potential, from which near about 40% contributes from direct emissions from machinery fueled by petroleum diesel for production of gravel and the remaining 38% contributes from explosives used in quarry for blasting purposes. The asphalt contributes 18% to Global Warming Potential impact, out of which 65% contributes emissions from oil refinery plants and the remaining 35% from direct emissions during transportation and heating before application to the pavement. Again, the contribution of machinery is showing 14% on Global Warming Potential impact, out of which only 15% contributes at the time of petroleum diesel production and the remaining 85% contributes at construction activities such as excavation, hot mix plant and road construction types of equipment. On average there is no significant variation between two life cycle impact assessment methods. The difference between total Global Warming Potential impacts differ between the two methods is only 1.5% due to the absence of some factors such as CO in the ReCiPe method. The impact factor of carbon dioxide for both methods is showing the same.

5.2. Ozone Depletion Potential (ODP)

Among the various categories of life cycle assessment, the production of asphalt is showing the highest contribution i.e. 53.2 and 60.1 for conditions C1 and C2 respectively. This is because of the direct emission of the halogenated compound such as Halon-1211, Halon-1301 and CFC-114 from petroleum refinery [45]. The emission of halogenated compounds depletes the ozone layer. The production of diesel plays the main contributor to the Ozone Depletion Potential impact among all processes. But for condition C2, biodiesel has been replaced with petroleum diesel and reduced the impact due to transportation near about 10.3% for the total Ozone Depletion Potential impact. Again, the impact value due to the transportation process is near about to same for both ReCiPe and CML methods.

5.3. Terrestrial Acidification Potential (TAP)

The Terrestrial Acidification Potential category for condition C2 has impacted 8% more than Condition C1. This is because of the higher emission of NOx during the combustion of biodiesel. The oxygen inside the biodiesel helps to increase the percentage of NOx due to an increase in temperature during the combustion process [46]. Under the transportation process, both petroleum diesel and bio-diesel contribute near about 30% in the process of fuel production. It is seen that the transportation of petroleum diesel impacts 37%, whereas transportation of bio-diesel impacts 53%.

From condition C1 it is found that TAP is already affected by gravel only, which contributes near about to 50% by both ReCiPe and CML method with very good agreement. Both methods are indicating that the cause behind contributing a higher percentage of gravel is the blasting of mineral mines. The blasting process contributes near about to 80% and rest of 20% are contributed by diesel-fueled truck for transportation of gravel. Again, it is found from the ReCiPe method that the most contributing substance to Terrestrial Acidification Potential by gravel process is NOx. It contributes near about 60% along with 40% NH_3. But in the CML method, the contribution of NOx is 75% along with 25% of NH_3. Now it is verified with the previous literature that the ReCiPe method contributes a higher value of NH3 and a lower value of NOx as compared to the CML method [40]. Next to gravel the second most category which contributes to TAP is the transport process and production of asphalt. Though the values by both ReCiPe and CML methods are near about equal, the ReCiPe method is slightly higher than CML due to the emission of NOx.

5.4. Freshwater Eutrophication Potential (FWEP)

From various literature, it is found that phosphorous and nitrogen are used as a reference compound for aquatic eutrophication potential [40]. Generally phosphorous is using for fresh lake water and nitrogen for saline marine water. From Figure 4 it is found that the

EDIP method shows higher value than the ReCiPe method for sand, gravel and machinery categories and lower value for asphalt and transport categories. The lower value (i.e 4% for asphalt and 7% for transportation) for the EDIP method is due to the emission of P-containing to the freshwater source [44]. The main contribution of phosphate to impact freshwater from the treatment of residues emitted from construction, machinery and production of raw materials. For the processing of gravel, the freshwater is impacted near about 90% due to direct emission during blasting and consumption of diesel by the ReCiPe method. No seashore is near to Ethiopia country; hence Merine Eutrophication Potential has not found here. In condition C2, using bio-diesel in transport trucks shows a large eutrophication impact than petroleum diesel because of the emission of phosphate during utilization of chemical fertilizer to the bean plants. Hence it is recommended that organic fertilizer has to be used for the cultivation of vegetable seeds for the production of bio-diesel.

5.5. Freshwater Ecotoxicity Potential (FWECP)

From Figure 4 it is found that the USEtox method is showing more impacts on Freshwater Ecotoxicity Potential by the categories of gravel, transport and machinery and lower impacts by the categories of asphalt and transport as compared to the ReCiPe method. Figure 3 shows a larger difference between ReCiPe and USEtox method, but it may be significant and acceptable. The USEtox model does not show absolute comparison with others [47]. The higher uncertainties in the parameters of both models give more differences because 10 to 20 numbers of most contributing substances make both models ideal rather than predicting the actual value. Both models are influenced by gravel and transportation at a higher percentage. The transport category is influenced more by the USEtox method (48%) than the ReCiPe method (40%). The higher percentage is due to residue treatment during the truck production process and tire and brake wear emissions. The impact on Freshwater Ecotoxicity Potential by gravel is showing more due to the use of explosive materials in mines and the treatment of residues during the process of explosive production. The substances which cause more impact to Freshwater Ecotoxicity Potential are copper than other influenced materials such as zinc, nickel, silver and vendium. By replacing petroleum diesel with biodiesel in condition C2, the Freshwater Ecotoxicity Potential is impacting 2.8 times than condition C2. This is because of the esterification of vegetable oils, treatment of various residues such as phosphoric acid, chemical fertilizer, methanol etc from the raw materials used for the production of biodiesel.

6. Conclusions

This work belongs to an inventory for the asphalt paved road construction based on collected data from Ethiopian Road Authority. By using different methods various environmental impacts like Global Warming Potential, Terrestrial Acidification Potential, Ozone Depletion Potential, Freshwater Eutrophication Potential and Freshwater Ecotoxicity Potential have been analyzed by taking various factors such as road construction materials, machinery and transport. Also, the environmental impacts have been evaluated by replacing petroleum diesel with biodiesel in transportation and machinery. From the evaluation process following conclusions are drawn.

- Among all impact categories, gravel and transport are two main processes, who are playing an important contributor to each environmental impact categories.
- Asphalt influences more to Ozone Depletion Potential category than other categories.

- The improvements in the production process of road construction materials such as sand, gravel, asphalt and transportation should be required to reduce their impacts on the environment and improve the quality of construction.
- The environmental impact from transport may vary on the location of the construction site and the availability of the distribution network.
- Each category of environmental mental impact evaluated by different methods are showing a similar percentage of contribution and the same substances and sub-process are showing as the most impactful.
- The replacement of petroleum diesel by biodiesel derived from the vegetable oils is showing lower environmental impacts than petroleum diesel and proved beneficial. Hence it is recommended that the production of biodiesel should be encouraged by Govt. of Ethiopia.
- Since the production process of gravel plays one important role in environmental impacts, it is suggested that construction waste may be a substitute for gravel. So that the natural resources of the country may be saved as well as our environment may be kept green.

Acknowledgement

Our grateful acknowledgment goes to Wollega University for its extensive support. No funding was received.

References

[1] Chandra S. Highway capacity research on inter-urban highways in india, Transp Dev Econ, 2015;1(1):20-4. https://doi.org/10.1007/s40890-015-0003-4
[2] Rath B, Debnath R, Paul A, Velusamy P, Balamoorthy D. Performance of natural rubber latex on calcined clay-based glass fiber-reinforced geopolymer concrete, Asian J Civ Eng, 2020;21(6): 1-16. https://doi.org/10.1007/s42107-020-00261-z
[3] Mazumder M, Sriraman V, Kim HH, Lee S-J. Quantifying the environmental impacts of crack sealing and filling treatment in hot mix asphalt pavement, Innovative Infrastructure Solution, 2018;3(1):1-12. https://doi.org/10.1007/s41062-018-0161-4
[4] Lu G, Wang Y, Li H, Wang D, Oeser M. The environmental impact evaluation on the application of permeable pavement based on life cycle analysis, Int J Transp Sci Technol, 2019; 8(4):351-357. https://doi.org/10.1016/j.ijtst.2019.05.006
[5] Jocelyn lvel, Rachel Watson, Bassim Abbassi, Ziad Salem Abu-Hamatteh. Life cycle analysis of concrete and asphalt used in road pavements, Environmental Engineering Research, 2020; 25(1): 52-61. https://doi.org/10.4491/eer.2018.399
[6] Trupia L, Parry T, Neves LC, Presti D Lo. Rolling resistance contribution to a road pavement life cycle carbon footprint analysis, Int J Life Cycle Assess, 2017;22(6):972-985. https://doi.org/10.1007/s11367-016-1203-9
[7] Santero NJ, Masanet E, Horvath A. Life-cycle assessment of pavements. Part I: Critical review, Resour Conserv Recycl, 2011;55(9-10):801-809. https://doi.org/10.1016/j.resconrec.2011.03.010
[8] Trunzo G, Moretti L, D'Andrea A. Life cycle analysis of road construction and use, Sustainability, 2019; 11: 1-13. https://doi.org/10.3390/su11020377
[9] Shtayat A, Moridpour S, Best B, Rumi S. An overview of pavement degradation prediction models, Journal of Advanced Transportation, 2022:1-15. https://doi.org/10.1155/2022/7783588
[10] Santero NJ, Masanet E, Horvath A. Life-cycle assessment of pavements Part II: Filling the research gaps, Resour Conserv Recycl, 2011;55(9-10):810-818. https://doi.org/10.1016/j.resconrec.2011.03.009

[11] Alaye QEA, Ling X, Dong Z, Bambou G. Evaluation of mixture performance recycled asphalt pavement materials as base layer with or without Rejuvenator into the asphalt, J Wuhan Univ Technol Sci Ed, 2020;35(3):579-597. https://doi.org/10.1007/s11595-020-2295-4
[12] Appiah JK, Berko-Boateng VN, Tagbor TA. Use of waste plastic materials for road construction in Ghana, Case Stud Constr Mater, 2017; 6:1-7. https://doi.org/10.1016/j.cscm.2016.11.001
[13] Yu M, You Z, Wu G, Kong L, Liu C, Gao J. Measurement and modeling of skid resistance of asphalt pavement: A review, Constr Build Mater, 2020;260:1-15. https://doi.org/10.1016/j.conbuildmat.2020.119878
[14] Lang AS. recycling materials from highways. National cooperative highway research program synthesis of highway, Practice No. 54, Transportation Research Board, Washington, DC, 1978.
[15] Mallick RB, Singh D, Veeraragavan A. Extension of asphalt pavement life by reduction of temperature, Transp. in Dev. Econ, 2016; 2(7): 1-7. https://doi.org/10.1007/s40890-016-0013-x
[16] Al-Hasan SJA, Balamuralikrishnan R, Altarawneh M. Eco-friendly asphalt approach for the development of sustainable roads, Journal of Human, Earth and Future, 2020; 1(3): 97-111. https://doi.org/10.28991/HEF-2020-01-03-01
[17] Bilema M, Bin Aman Y, Hassan NA, Al-Saffar Z, Ahmad K, Rogo K. Performance of aged asphalt binder treated with various types of rejuvenators, Civil Engineering Journal, 2021; 7(3): 502-517. https://doi.org/10.28991/cej-2021-03091669
[18] Nawir D, Mansur AZ. The impact of hdpe plastic seeds on the performance of asphalt mixtures, Civil Engineering Journal, 2021; 7(9): 1569-1581. https://doi.org/10.28991/cej-2021-03091744
[19] Hoxhaa E, Vignisdottirb HR, Barbieric DM, Wangcd F, Bohnec RA, Kristensenb T, Passera A. Life cycle assessment of roads: Exploring research trends and harmonization challenges, Science of The Total Environment, 2021;759:1-16. https://doi.org/10.1016/j.scitotenv.2020.143506
[20] Singh A, Pant D, Olsen SI. Life cycle assessment of renewable energy sources. Springer; 2013. https://doi.org/10.1007/978-1-4471-5364-1
[21] Trigaux D, Wijnants L, De Troyer F, Allacker K. Life cycle assessment and life cycle costing of road infrastructure in residential neighbourhoods, Int J Life Cycle Assess, 2017;22(6):938-51. https://doi.org/10.1007/s11367-016-1190-x
[22] Szymański P, Pikos M, Nowotarski P. Concrete road surface with the use of cement concrete-selected results, Procedia Eng, 2017;208:166-73. https://doi.org/10.1016/j.proeng.2017.11.035
[23] Giustozzi F, Crispino M, Flintsch G. Multi-attribute life cycle assessment of preventive maintenance treatments on road pavements for achieving environmental sustainability, Int J Life Cycle Assess, 2012;17(4):409-19. https://doi.org/10.1007/s11367-011-0375-6
[24] Nguyen T, Lechner B, Wong YD. Response-based methods to measure road surface irregularity: a state-of-the-art review, Eur. Transp. Res. Rev, 2019;11: 1-18. https://doi.org/10.1186/s12544-019-0380-6
[25] Fontaras G, Zacharof NG, Ciuffo B. Fuel consumption and CO2 emissions from passenger cars in Europe - Laboratory versus real-world emissions, Progress in Energy and Combustion Science, 2017; 60: 97-131. https://doi.org/10.1016/j.pecs.2016.12.004
[26] Sala S, Amadei AM, Beylot A, Ardente F. The evolution of life cycle assessment in European policies over three decades, Int J Life Cycle Assess, 2021;1-20. https://doi.org/10.1007/s11367-021-01893-2

[27] Hassouna F, Jung YW. Developing a higher performance and less thickness concrete pavement: using a nonconventional concrete mixture, Adv Civ Eng, 2020; 1-8. https://doi.org/10.1155/2020/8822994
[28] Hauschild M. Environmental impact. In: the international academy for production engineering, Laperrière L., Reinhart G. (eds) CIRP Encyclopedia of Production Engineering. Springer, Berlin, Heidelberg, (2014).
[29] Emmenegger R. The Roads of Decentralization: the history of rural road construction in Ethiopia. 2012.
[30] Lima MSS, Hajibabaei M, Hesarkazzazi S, Sitzenfrei R, Buttgereit A, Queiroz C, Haritonovs V, Gschösser F. Determining the environmental potentials of urban pavements by applying the cradle-to-cradle lca approach for a road network of a midscale german city, Sustainability, 2021; 13(22): 1-14. https://doi.org/10.3390/su132212487
[31] Salah M, Haggar El. Rural and developing country solutions, Environmental Solutions, 2005: 313-400. https://doi.org/10.1016/B978-012088441-4/50015-0
[32] ERA. The Federal Democratic Republic Of Ethiopia Ethiopian Roads Authority Pavement Design Manual Vloume I: Flexible Pavements. Pavement Des. 2013; I(March):281.
[33] Final project report, Training Program for Improved Performance of Surface Treatments in Ethiopia, Ethiopian Roads Authority. 2019: 1-84.
[34] Wernet G, Bauer C, Steubing B, Reinhard J, Moreno-Ruiz E, Weidema B. The ecoinvent database version 3 (part I): overview and methodology, Int J Life Cycle Assess, 2016;21(9):1218-30. https://doi.org/10.1007/s11367-016-1087-8
[35] Wernet G, Bauer C, Steubing B, Reinhard J, Moreno-Ruiz E, Weidema B. The ecoinvent database version 3 (part I): overview and methodology, Int J Life Cycle Assess, 2016;21(9):1218-30. https://doi.org/10.1007/s11367-016-1087-8
[36] Mondal MAH, Bryan E, Ringler C, Mekonnen D, Rosegrant M. Ethiopian energy status and demand scenarios: prospects to improve energy efficiency and mitigate GHG emissions, Energy, 2018;149:161-72. https://doi.org/10.1016/j.energy.2018.02.067
[37] Praveenkumar T. R, Velusamy P, Balamoorthy D. Pyrolysis oil for diesel engines from plastic solid waste: a performance, combustion and emission study, Int J Ambient Energy, 2020;1-5. https://doi.org/10.1080/01430750.2020.1818124
[38] Ndukwu MC, Onyeoziri CI. African oil bean seed as feedstock for bio-oil and biodiesel production and on the effects of thermal pre-treatments on the quality of the bio-oil, Biomass Convers Biorefinery, 2020;1-12. https://doi.org/10.1007/s13399-020-00754-6
[39] Kousis I, Fabiani C, Ercolanoni L, Pisello AL. Using bio-oils for improving environmental performance of an advanced resinous binder for pavement applications with heat and noise island mitigation potential, Sustain Energy Technol Assessments, 2020;39:1-13. https://doi.org/10.1016/j.seta.2020.100706
[40] Hope AP, Canty TP, Salawitch RJ, Tribett WR, Bennett BF. Forecasting global warming. In: Paris climate agreement: Beacon of hope. Springer, Cham; 2017: 51-113. https://doi.org/10.1007/978-3-319-46939-3_2
[41] Nunez P, Jones S. Cradle to gate: life cycle impact of primary aluminium production. Int J Life Cycle Assess. 2016;21(11):1594-1604. https://doi.org/10.1007/s11367-015-1003-7
[42] Pettersen JB, Song X. Life cycle impact assessment in the arctic: challenges and research needs. Sustainability. 2017;9(9):1-20. https://doi.org/10.3390/su9091605
[43] Ciroth, A. ICT for environment in life cycle applications open LCA - a new open source software for life cycle assessment, Int. J. Life Cycle Assess, 2007; 12: 209-210. https://doi.org/10.1065/lca2007.06.337
[44] Thalmann P, Vielle M. Lowering CO2 emissions in the Swiss transport sector. Swiss J Econ Stat. 2019;155(1):1-12. https://doi.org/10.1186/s41937-019-0037-3

[45] Barletta B, Meinardi S, Simpson IJ, Rowland FS, Chan C-Y, Wang X, et al. Ambient halocarbon mixing ratios in 45 Chinese cities, Atmos Environ, 2006;40(40):7706-19. https://doi.org/10.1016/j.atmosenv.2006.08.039
[46] Özener O, Yüksek L, Ergenç AT, Özkan M. Effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics, Fuel, 2014;115:875-83. https://doi.org/10.1016/j.fuel.2012.10.081
[47] Rosenbaum RK, Bachmann TM, Gold LS, Huijbregts MAJ, Jolliet O, Juraske R, et al. USEtox-the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment, Int J Life Cycle Assess, 2008;13(7):532-46. https://doi.org/10.1007/s11367-008-0038-4