Assessment of Carbon Footprint and Emergy Vis-À-Vis Sub Grade Strength in Flexible Pavement Construction

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Abstract**: *Construction of flexible pavements in India is increasing rapidly and causing emission of Green House Gases (GHG) into the atmosphere which in turn increases the global warming. This paper focuses on finding out the emergy, that is the embodied energy of materials and process in construction of flexible pavement and the corresponding emission caused during the entire construction. A tool model was developed in Microsoft Excel to calculate the energy and GHG emission in construction of flexible pavement. The Life Cycle Assessment in construction of pavement has been divided into four stages namely material production stage, material processing stage, transportation stage and site execution stage, and at each stage the emergy and emission are calculated. It is seen that, during the processing of material that is the process which involves the mixing of materials into asphaltic mix in central hot mix plant and during of mixing aggregates in pug mill the energy consumption and the emission are more. A case study has been done for construction of one KM of flexible pavement of 7.0 m width with constant design parameters and by varying the sub grade California Bearing Ratio (CBR) values.The result shows that the CBR values have high influence in energy and emission.***

Index Terms**: *Life Cycle Assessment, Carbon Foot Print, Emergy, Emission, Flexible Pavement.***

I. INTRODUCTION

India has very large network of highways having a total length of about 56 lakhs kilometers[1]. About 90% of the passenger traffic uses highways and 65 % of transportation of goods done through this road network. Every year the construction of road increase rapidly compared to the other transportation network. It has been observed that the transport sector consumes about 18% of the total energy [2]. Every year 142 Million tons of CO_2 released by the transportation sector and 81% of this comes from the road based emission. Unless or otherwise any action taken, by the year 2030 the overall emission due to transport will become 1000 million ton.

A. LCA Overview

Life cycle assessment is a method developed to understand, assess and to quantify the impact due to environment of a particular product. In recent years LCA is increasing applied to analyze the GHG emission and other environmentally concerned substances involved in road pavements. Reference [03] states that the growing number of literatures regarding the LCA of pavements shows the awareness regarding the improving of sustainability of infrastructure system.

The normal structure of LCA was framed by International Standards Organization. As shown in the following Fig. 1 there are three basic stages: Goal and scope definition, inventory analysis, impact analysis.

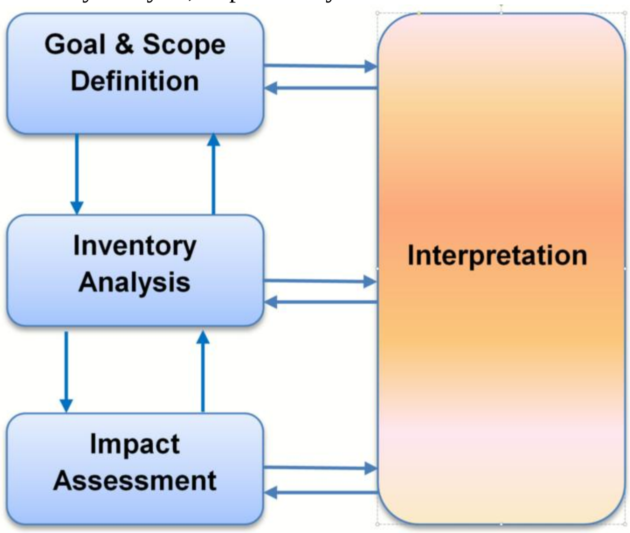

Fig. 1: Life cycle Assessment Frame work as per ISO 14040.

B. Goal Definition and Scope

For any process the first step in LCA is the definition of goal and scope. In any process for LCA consideration, the goal is to identify all the environmental impacts of a material and find a solution to reduce the harmful environmental effects.

C.Inventory Analysis

Inventory analysis is analyzing an inventory flow for a process or a product from cradle stage to the end stage. It includes inputs from water, energy and raw materials emission to to air water and soil.

D. Impact Assessment

LCA impacts assessment constitutes of influence of the activities conducted by LCA. The assessment categories include global warming potential, acidification, eutrophication, photochemical smog etc.

E. Objectives

The main objective of is study is to develop a first integral approach to the GHG emissions linked to the construction of a flexible pavement of the road, using the available information and data and to develop a model in Microsoft Excel .The current study aims at developing a tool model, which gets input from user about the pavement composition and to give output as the total energy

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consumed for construction of the road as well as the total emission causing Global warming. And using the tool developed a comparison of energy consumption and emission of carbon di oxide equivalent for a particular road pavement of 1km length with different types of the sub grade of soil having different values of CBR, and to find which process involves more emission and energy.

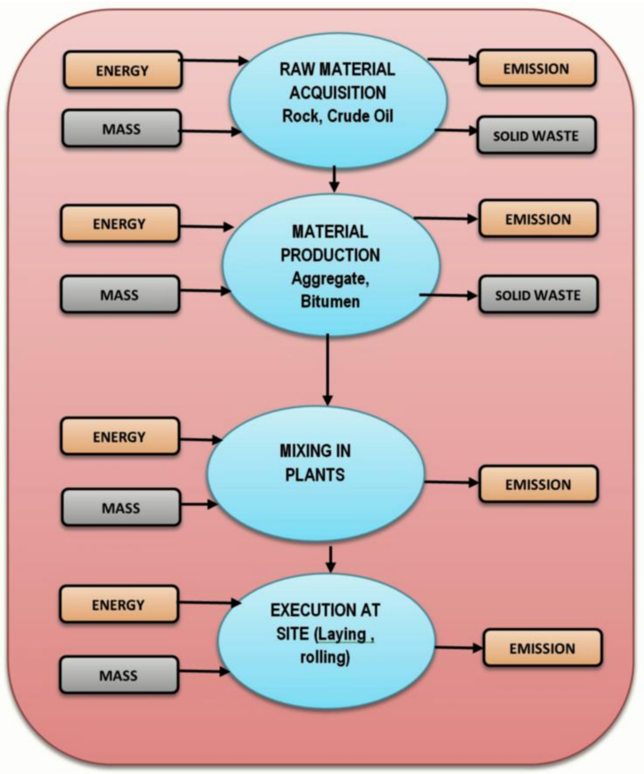

Fig. 2: Life cycle Assessment of flexible pavement system boundaries.

In this paper the analysis covers the life cycle of the projects, and intends to provide a functional and operative knowledge of the process involved that allows to provide

a) Life cycle based environmental evaluations of road construction projects, the energy expended during the execution of a highway project and emission of the carbon di oxide equivalent during each stage of the construction.
b) To identify the main elements of the system which contributes Green House Gas emission, evaluating and quantifying them.

F. Scope

The scope of the analysis is calculation of the emission and energy consumed starting from the extraction of raw materials upto the construction of the road. The deforestation while forming the road and the maintenance stage are not considered. The stages considered are raw material extraction, conveying to factory, production of finished material, transportation and mixing the products in mixing plant, again transporting to laying site and formation of road pavement.

G. Inventory Analysis

Starting from raw material acquisition and upto construction of pavement, each any every stage is analysed for inventory. The energy required to perform an operation for a fixed quantity of execution is calculated based on journal papers and previous Ph.D theses. The corresponding emission causing Green House Effect has been calculated for each stage.

H. Impact Assessment

The total impact of energy consumed for full construction of road and emission of greenhouse gases are consolidated and tabulated.

I. Global Warming Potential

To compare the global warming impact of different gases, a common factor was developed which is known as Global Warming Potential (GWP) .It is a measure of how much energy the emissions of one ton of a gas will absorb over a given period of time, compared to the emissions of one ton of carbon dioxide (CO_2). Usually the time period considered for GWP is 100 years. The main advantage of the GWP is that it allows a common measuring unit, which is used to allow adding up the emission of different gases.

In the highways sector the major gases play in Global Warming Potential are Carbon di oxide, Nitrous oxide and methane.

Table 1 CO_2 Equivalency factors

Gases	CO_2 Equivalency
Carbon Di Oxide CO_2	1
Methane CH_4	25
Nitrous Oxide N_2O	298

Source: United States Environmental Protection Agency

J.Emergy

Emergy is the collection of all forms of energy which are directly or indirectly utilized to make a particular product or process and converting it to one form of energy.

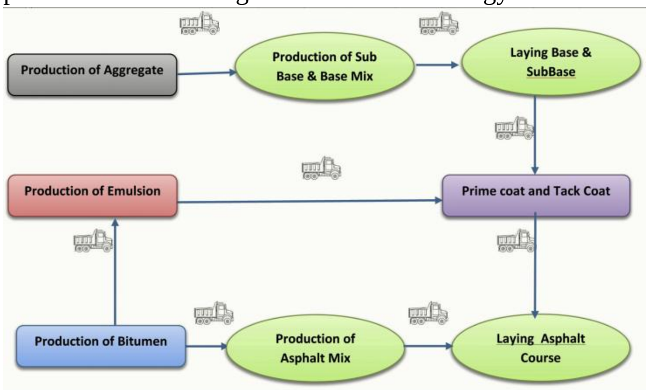

Fig. 3: Process of Construction of Asphaltic Pavement

II. LITERATURE REVIEW

Xiaoyan et al. [04] studied comprehensive Life Cycle Assessment with three types of pavement system. And found that Hot Mix asphalt with Reclaimed Asphalt Pavement has more social and economic performance, and the Hot Mix asphalt with Warm Mix additives shows good environmental performance.

A comparison was made by Wang et al.[05] regarding the emission and energy consumption in construction of permeable asphalt pavement with ordinary asphalt pavement and concluded that that emission and energy consumption in permeable pavement is lesser than the conventional pavement.

The PhD thesis of Trupula, Laura [06]. provides review of models which influence

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the vehicle fuel consumption during the maintenance stage of the road pavement and also analyze the the emission due to resistance to the rolling of vehicles over the pavement.

By modifying the asphalt mixtures with suitable additives, Ali Azhar Butt et al. [07] found that the properties of the mixture can be enhanced.

Shashwath Sreedhar et al. [08] developed a model tool kit for Life Cycle Assessment which quantifies the emission in the Highways construction in India and found that the emission is more in the traffic design stage

Songsu Son et al. [09] studied with two types of controlled asphalt mixes with four types of newly developed mix using the aggregates which are available locally and slag, fibre found that the performance of the new mixtures are better than the conventional asphaltic mix.

Jesús M. Barandica et al. [10] developed a tool for Life Cycle Assessment of pavements in order to control emission in the road construction and found that the construction part of the road construction is the primary cause of emission and the maintenance part has the secondary role in Life Cycle Assessment.

Feedstock energy is the potential energy present in the material, but is not used as the source of energy. Butt, A.A[11] .states that the pavement material the crushed aggregate has no feedstock energy but the Bitumen has 40.2 MJper kg. and he found that the energy consumption and emission are more in asphalt without any polymer modification

Macro et al. 12] studied the Life Cycle Inventory with the usage of bitumen, industrial by-products like steel slag, recycled material and virgin aggregates .The result showed that distance of transportation and the recycled material plays a vital role in environmental as cost impact.

Hao Wang [13].studied energy and emissions of four pavement preservation treatment which were quantified at the construction and usage stages. It was concluded that a thin overlay was found to have the highest energy consumption and emissions.

III.METHODOLOGY OF STUDY

A. General

The present paper is intended to study the energy consumed and the green house gas emission during the construction of road pavement. The first thing is to develop a tool model using Microsoft Excel for calculating the energy and emission of a road construction, and using the same a case study for pavements with various subgrade properties, and to make comparisons.

There are two types of construction of road pavement, and the pavement means the portion which transmits the vehicular load from surface to the sub grade via base course. The two types are flexible pavement as shown in Fig. 4.and rigid pavement. Atakilti et al. [14] stated that in flexible pavement the load applied on wearing surface of the top of road is being dispersed widely and transmitted to the bottom of road that is sub grade through the binder course and non-bituminous course whereas the in rigid pavement the load on the top of pavement which is a concrete slab, is being transmitted to a wider area of by the slab with smaller depth.

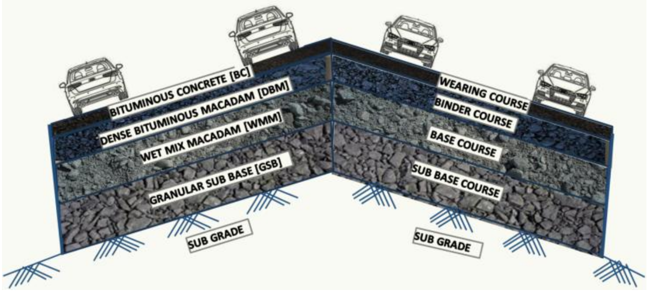
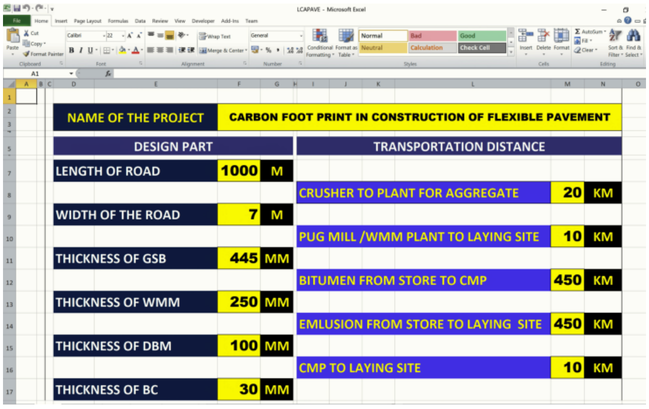


Fig. 4: Cross section of a flexible pavement

B. Tool model

Based on the design result, a tool model named LCAPAVE was developed in Excel Spread Sheet comprising of five Sheets.

Input Sheet
Material Sheet
Result sheet
Energy Chart Sheet
Emission Chart Sheet



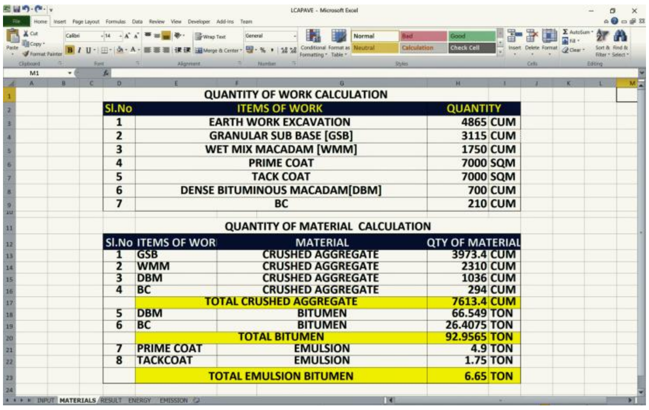
NAME OF THE PROJECT	CARBON FOOT PRINT IN CONSTRUCTION OF FLEXIBLE PAVEMENT				
DESIGN PART			TRANSPORTATION DISTANCE		
LENGTH OF ROAD	1000	M			
			CRUSHER TO PLANT FOR AGGREGATE	20	KM
WIDTH OF THE ROAD	7	M			
			PUG MILL /WMM PLANT TO LAYING SITE	10	KM
THICKNESS OF GSB	445	MM			
			BITUMEN FROM STORE TO CMP	450	KM
THICKNESS OF WMM	250	MM			
			EMLUSION FROM STORE TO LAYING SITE	450	KM
THICKNESS OF DBM	100	MM			
			CMP TO LAYING SITE	10	KM
THICKNESS OF BC	30	MM			

Fig. 5: Input Sheet of the tool model LCAPAVE

Fig. 5.shows the input form of spread sheet.. Here the name of the project is to be entered first, followed by the design data and lead, that is distance data. The layer thickness obtained from the software may be entered in LCAPAVE Module1 under design part. The second part of the input is the conveyance part commonly called as lead particulars. The crushed aggregate has to be transported from the crusher to the mixing plant. Also the bitumen for binder and wearing course and the emulsion bitumen for a applying prime coat and tack coat has to be transported from the storage godown the central hot mix plant and site. With the entry of the above data the module 1 completes.

C. Material Sheet

In this sheet shown in Fig. 6, the quantity of each items of works namely, earth work excavation, Granular Sub Base, Sub Base, Prime Coat. Tack Coat Dense Bituminous course, and the top wearing course, has been calculated based on the input given in the input sheet.



QUANTITY OF WORK CALCULATION

Sl.No	ITEMS OF WORK	QUANTITY	
1	EARTH WORK EXCAVATION	4865	CUM
2	GRANULAR SUB BASE [GSB]	3115	CUM
3	WET MIX MACADAM [WMM]	1750	CUM
4	PRIME COAT	7000	SQM
5	TACK COAT	7000	SQM
6	DENSE BITUMINOUS MACADAM[DBM]	700	CUM
7	BC	210	CUM

QUANTITY OF MATERIAL CALCULATION

Sl.No	ITEMS OF WOR	MATERIAL	QTY OF MATERIAL	
1	GSB	CRUSHED AGGREGATE	3973.4	CUM
2	WMM	CRUSHED AGGREGATE	2310	CUM
3	DBM	CRUSHED AGGREGATE	1036	CUM
4	BC	CRUSHED AGGREGATE	294	CUM
	TOTAL CRUSHED AGGREGATE		7613.4	CUM
5	DBM	BITUMEN	66.549	TON
6	BC	BITUMEN	26.4075	TON
	TOTAL BITUMEN		92.9565	TON
7	PRIME COAT	EMULSION	4.9	TON
8	TACKCOAT	EMULSION	1.75	TON
	TOTAL EMULSION BITUMEN		6.65	TON

Fig. 6: Material calculation Sheet of the tool model LCAPAVE.

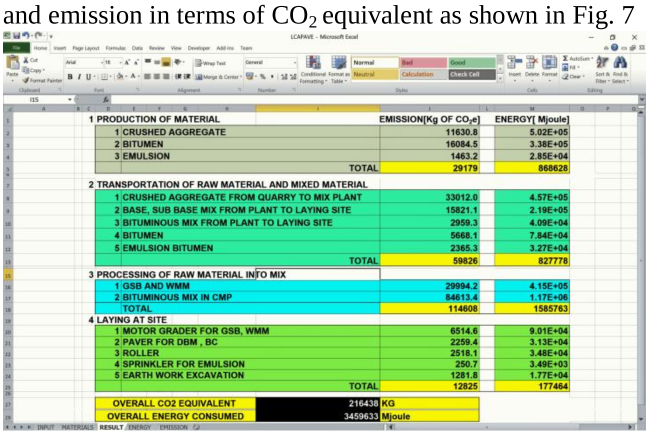
The second part in the material sheet calculates the individual materials required for the quantity of items of woks calculated earlier. For calculation of materials required like crushed aggregates, bitumen, Emulsion Bitumen for the works of Granular Sub Base (GSB), Wet Mix Macadam(WMM) , Prime coat, Tack coat, DBM, BC the data obtained from Standard Data Book For Analysis Of Rates [15]. Ministry of Road Transport and Highways has been adopted. This has been adopted throughout India. The crushed aggregate quantity requirement for the project has been calculated in terms of cubic meters and the requirement of Bitumen and Emulsion Bitumen are calculated.

D.Result Sheet

The energy expended and the emission are calculated in four phases.

1. Energy and emission during Production of material
2. Energy and emission During Transportation of raw material and mixtures.
3. Energy and emission during processing of raw material into mixtures
4. Energy and emission during laying , paving rolling at site.

And finally this sheet calculates the total energy expended, and emission in terms of CO_2 equivalent as shown in Fig. 7



		EMISSION[Kg OF CO2e]	ENERGY[Mjoule]
1	PRODUCTION OF MATERIAL		
1	CRUSHED AGGREGATE	11630.8	5.02E+05
2	BITUMEN	16084.5	3.38E+05
3	EMULSION	1463.2	2.85E+04
	TOTAL	29179	868628
2	TRANSPORTATION OF RAW MATERIAL AND MIXED MATERIAL		
1	CRUSHED AGGREGATE FROM QUARRY TO MIX PLANT	33012.0	4.57E+05
2	BASE, SUB BASE MIX FROM PLANT TO LAYING SITE	15821.1	2.19E+05
3	BITUMINOUS MIX FROM PLANT TO LAYING SITE	2959.3	4.09E+04
4	BITUMEN	5668.1	7.84E+04
5	EMULSION BITUMEN	2365.3	3.27E+04
	TOTAL	59826	827778
3	PROCESSING OF RAW MATERIAL INTO MIX		
1	GSB AND WMM	29994.2	4.15E+05
2	BITUMINOUS MIX IN CMP	84613.4	1.17E+06
	TOTAL	114608	1585763
4	LAYING AT SITE		
1	MOTOR GRADER FOR GSB, WMM	6514.6	9.01E+04
2	PAVER FOR DBM , BC	2259.4	3.13E+04
3	ROLLER	2518.1	3.48E+04
4	SPRINKLER FOR EMULSION	250.7	3.49E+03
5	EARTH WORK EXCAVATION	1281.8	1.77E+04
	TOTAL	12825	177464

OVERALL CO2 EQUIVALENT	216438	KG
OVERALL ENERGY CONSUMED	3459633	Mjoule

Fig. 7: Result Sheet of the tool model LCAPAVE

Data for emergy and emission for the production of aggregate, Bitumen . The rock pieces obtained from blasting of rock masses is brought into the crusher for crushing into final form of desired sizes. Data for blasting, crushing etc.and energy consumption and the emission of gases were acquired from [16] . Also the data for production of Bitumen and transportation by truck were acquired from [16].

Data foremergy and emission for the production of Emulsion Bitumen.TimoBlomberg [17].analysed and collected inventory data for Emulsion Bitumen, Polymer modified Bitumen. The same has been adopted for emulsion bitumen which is used for prime coat and tack coat.

Data for other items. The emergy and emission data for production of asphalt mix in central hot mix plant has been derived based on the fuel consumption .This plant is the major plant used in the construction of roads. The bitumen and aggregates are mixed in this unit with the required proportion as per the job mix formula. Different graded aggregates are loaded in different bins,and with required proportions they are mixed and then heated in a rolling drum. Bitumen is stored in separate tank, and mixed with the hot aggregate present in the drum.

The Standard Data Book for Analysis of Rates published by Indian Road Congress -2003 [15]. tabulates the materials required for each items of work like production of asphalt mixture, laying using paver , rolling etc. as well as the corresponding requirement of machineries for executing a unit quantity of work. The fuel consumption of machineries are derived by adopting the standard consumption of fuels for machineries obtained from field and research papers and finally the energy consumption and the emission data are derived based on the fuel consumption of executing a unit quantity of item of work. Also for the paver , loader , water tanker calculation of energy and emission were done based on the out turn given in the Standard Data,

Based on data collected from research publications, the fuel consumption of machineries based on out turn of machineries given in Standard Data Book [15]. , and fuel consumption for works obtained from Data Tool [18]. issued by the Highways Department of State Government, the energy consumption and emission for each item of works are arrived and tabulated as shown in Table 2.

Table 2: Data for energy and emission

Emission of Green House Gases in grams							
Item of Material/work	Unit	Energy (MJ)	CO_2	N_2O	CH_4	CO_2e	Reference

Bitimen Production	Ton	3.64E+03	1.73E+05	1.06E-01	3.53E-02	1.73E+05	Stripple.H[16].
Emulsion Production	Ton	4.29E+03	2.04E+05	1.06E-01	6.40E+02	2.20E+05	TimoBlomberg[17].
Aggregate Production	Ton	6.59E+01	1.42E+03	3.61E-01	3.82E-03	1.53E+03	Stripple.H[16].
Excavator360 cum/hr	m^3	3.65E+00	2.62E+02	5.29E-03	1.70E-04	2.63E+02	Derived Data
Front End Loader	m^3	2.32E+01	1.66E+03	3.36E-02	1.08E-03	1.67E+03	Derived Data
Vibratory Roller	m^3	6.03E+00	4.33E+02	8.75E-03	2.81E-04	4.36E+02	Derived Data
Paver Finisher	m^3	3.44E+01	2.47E+03	4.98E-02	1.60E-03	2.48E+03	Derived Data
Truck 14 T	Km	1.31E+01	9.43E+02	1.90E-02	6.12E-04	9.49E+02	Derived Data
Bitumen Sprayer	m^2	2.49E-01	1.79E+01	2.24E-05	9.00E-07	1.79E+01	Stripple.H[16].
Motor Grader	m^3	1.85E+01	1.33E+03	2.69E-02	8.64E-04	1.34E+03	Derived Data
WMM,GSB Mixing	m^3	8.53E+01	6.13E+03	1.24E-01	3.98E-03	6.17E+03	Derived Data
Asphalt Mixing	m^3	1.29E+03	9.24E+04	1.87E+00	6.00E-02	9.30E+04	Derived Data

Based on the above table this tool model calculates the energy consumption in Joule and the GHG emission in terms of tons CO_2 equivalent.

D. Energy Chart Sheet

The sheet in Fig. 8 shows the amount of energy consumed for each process of work in a tabular form along with a comparative bar chart. From this we can get a clear idea about which process involves more energy and what is the percentage of energy consumed for each activity.

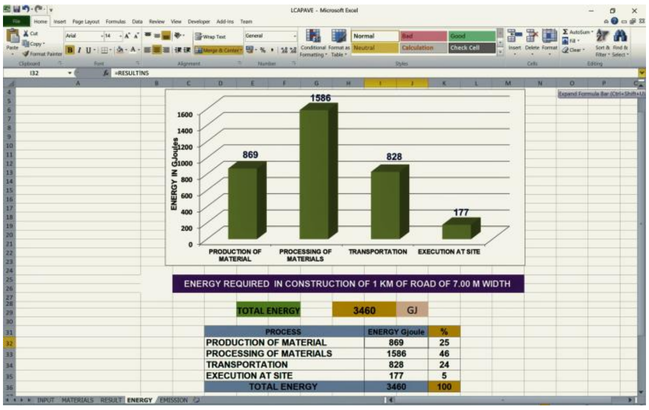


Fig. 8: Sheet showing the energy consumption from the tool model LCAPAVE

E. Emission Chart Sheet

Just like the energy chart sheet, this module, shown in Fig. 9, gives a clear idea of how much GHG emitted in terms of tons CO_2e in each process of work . Both tabular form and graphical representation are also made along with the percentage of emission in each category.

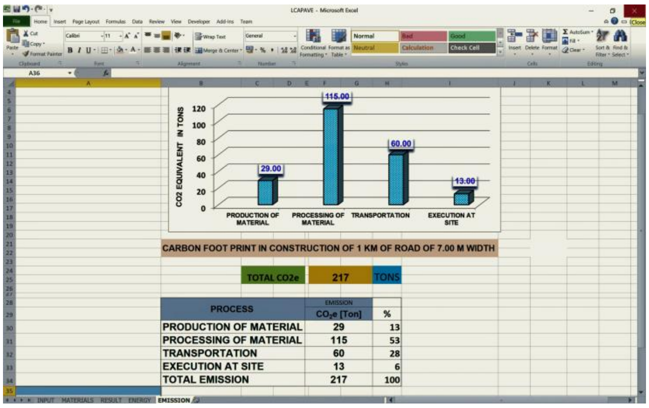


Fig. 9: Sheet showing the emission from the tool model LCAPAVE

4.CASE STUDY

A flexible pavement with a functional unit 1km length and 7.00 m width two lane state Highways is taken for analysis. The design data entered into the developed tool LCAPAVE and the corresponding energy consumption and emission are analyzed. Then keeping all the design parameters as constant for different subgrade CBR values the energy and emission are tabulated and analyzed.

A. Design of Flexible pavement

The pavement has been designed as per the Indian Standard code IRC 37(2012)[19] The functional unit considered here is one KM length having 7.00 m width with the following assumptions.

Classification of Road State Highways
No. of lane 2
Length of the Road 1.00 KM
Width of the carriageway 7.00 m
CBR of the Sub Grade varying from 3 to 8
Traffic Intensity 250 CVPD
Traffic Growth Rate 5%
Design Life for SubBase &Base 15 years
Design life for bituminous course: 5 years
Bitumen grade VG30

Using the above data, the thickness of various layers of the flexible pavement is designed. The design for the above pavement has been made as per the guidelines prescribed in the Standard Specification of Roads and Bridges, Ministry of Road Transport and Highways, New Delhi [20].and Indian Standard Code IRC 37 [19]. The Software IITPAVE was used to check the stress and strain developed in Sub Base and Bituminous Course while designing.

The design of flexible pavement has been made using TNHD_PAVE[22]. a tool developed by the State Highways Department, TamilNadu adopting the above mentioned input. As per IRC 37 -2018[19].the State Highways pavement has to be designed for 15 years. Here the Sub base, base layers are designed for 15 years while the bituminous courses are designed for 5 years by adopting stage construction which is the usual practice followed.

B. California Bearing Ratio

California Bearing Ratio commonly called as CBR is a property of the soil which indicates the strength of the subgrade. This value is used to design the overall thickness of pavement and to calculate the thickness of each layer. In this paper for a particular road project, how the CBR of the sub grade affects the Life Cycle Assessment of the pavement is studied.

C. Results and Discussion

Using the software TNHD_PAVE and other IRC codes, the pavement is designed for CBR value 3.Thickness of GSB layer, WMM layer , DBM & BC layers were arrived , and the same has been given as input in the developed LCA tool LCAPAVE, and the output in terms of emission and energy consumption is tabulated below.

Green House Gas emission in equivalency of CO_2 is obtained from the emission sheet of the developed LCA tool.

Table 3 Emission from various process for CBR value 3

Sl.No	Process	Emission CO_2e [Ton]	%
1	Production of material	29	13
2	Processing of material	115	53
3	Transportation	60	28
4	Execution at site	13	6
	Total Emission	**217**	**100**

It is seen from the above table that, the emission will be more in the processing of materials, that is more emission during production of Hot Asphalt Mix and production of base and sub base mixes. During the production Hot Mix Asphalt, more fuel is required to heat the bitumen, aggregates and rotating the drum for mixing the bitumen with aggregates. Hence automatically the emission is more. It is evident from the above table that more than 50% of the emission is caused due to mixing of materials.

Next to the material mixing, the transportation phase emits more greenhouse gases. The raw materials like aggregates, bitumen are being transported from manufacturing place to the mixing site, and the mixed materials are transported from plants to the laying site involves truck transport which emits more GHG.

The emission due to production of materials used in the construction of pavement comes to the next place. Comparing the transportation of material and mixing of material, the emission is lesser due to the face that the production of aggregate and bitumen involves electricity and gas unlike diesel used in other processes.

Finally the execution of work at the site namely earthwork excavation, laying and rolling of Granular Sub Base, Sub Base, spraying of Prime Coat, Tack Coat, paving and rolling Dense Bituminous Macadam, and Bituminous Concrete wearing course , emits lesser green house gases. The machineries like paver grader uses diesel as fuel, but having a very good out turn in paving the material, the emission is less in this process.

For the same design the energy consumption is obtained from the energy sheet of the tool LCAPAVE and the same is tabulated here.

Table 4 Energy consumption from various process for CBR value 3

Sl.No	Process	Energy in GJoules	%
1	Production of material	869	25
2	Processing of material	1586	46
3	Transportation	828	24
4	Execution at site	177	5
	Total Emission	**3460**	**100**

From the above table it is evident that the energy consumption in processing of raw material and for transportation are almost same while the mixing of material requires more energy, and the execution at site requires least energy.

In the above discussion comparison is made for the process of works involved for a particular CBR value that is for the value 3. Now as a case study the CBR of sub grade is varying from 3 to 8 with unit an increment in each category and the outcome of results is analyzed. The following table 5 shows the comparison among the pavements with different CBR.

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Table 5 Emission of GHG in construction of 1km flexible pavement of 7 m width with varying CBR from 3 to 8.

	Emission of GHG in terms of tons CO_2e					
Process	**CBR3**	**CBR4**	**CBR5**	**CBR6**	**CBR7**	**CBR8**
Production of material	29	26	24	23	22	21
Processing of material	115	99	86	82	78	74
Transportation	38	34	31	30	28	27
Execution at site	13	11	10	10	9	9
Total	**195**	**170**	**151**	**145**	**137**	**131**

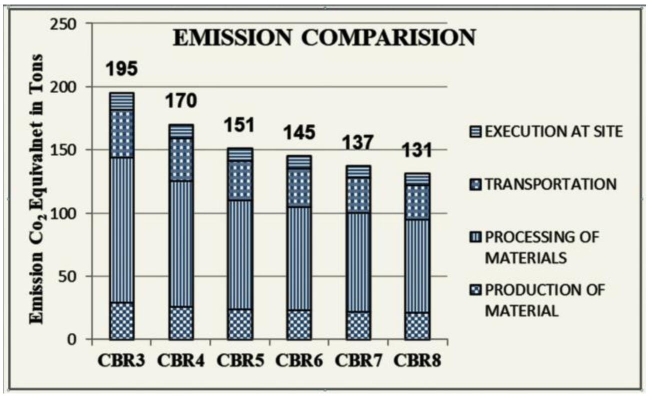

Fig. 10: Emission of CO_2 equivalent in tons for various CBR for a pavement of 1km length , 7.00 m width.

The above chart shows the total emission for various CBR values keeping other parameters like length and width of pavement, traffic intensity etc. as constant. It is very clear that the CBR of the sub grade plays a major role in deciding the Life Cycle Impact. For the CBR value 3 the total emission is 195 tons per KM length of pavement of 7.00 m width, and while the CBR vale 8 the emission reduces to 131 tons.

When comparing the CBR3 with other CBR values, there is a gradual decrease in emission while the CBR increases, especially at early increase in CBR , the reduction of emission is more.

Table 6 Energy consumed in G Joules in construction of 1km flexible pavement of 7 m width with varying CBR from 3 to 8

Process	**CBR 3**	**CBR 4**	**CBR 5**	**CBR 6**	**CBR 7**	**CBR 8**
Production of material	869	765	704	672	641	612
Processing of material	1586	1364	1196	1136	1076	1019
Transportation	528	471	428	409	391	375
Execution at site	177	158	143	137	130	125
Total	**3160**	**2758**	**2471**	**2354**	**2238**	**2131**

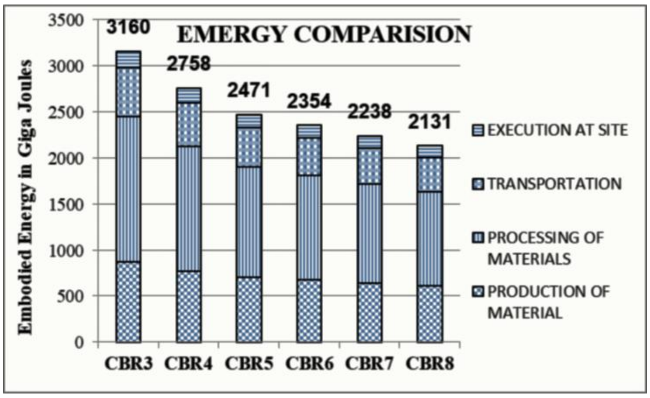

Fig. 11: Energy consumption for a flexible pavement of 1km length , 7.00m width with varying subgrade CBR from 3 to 8

The above chart shows the the energy consumption in gigajoules for the pavement while changing the CBR values. From the chart it is clear that the increase in the CBR values shows reduction in energy consumption. Especially at early change in CBR the corresponding change in energy consumption is more.

The following charts show the embodied Energy consumption and the emission in construction of a flexible pavement of 1km length , 7.00m width with varying subgrade CBR from 3 to 8 during each stage of the construction of flexible pavement.

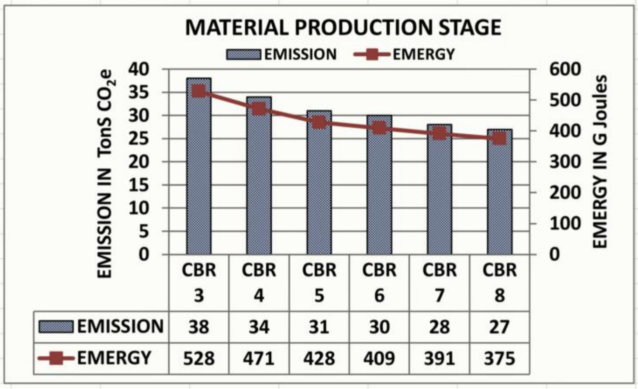

Fig. 12: Energy consumption and the emission in material production stage.

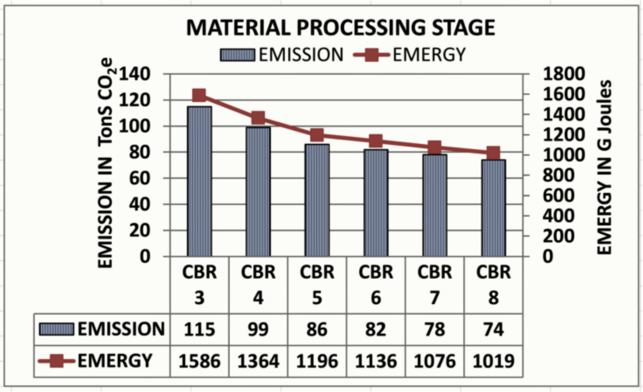

Fig. 13: Energy consumption and the emission in material processing stage

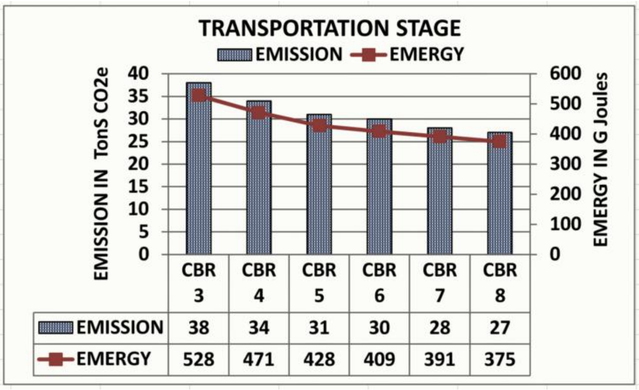

Fig. 14: Energy consumption and the emission transportation stage

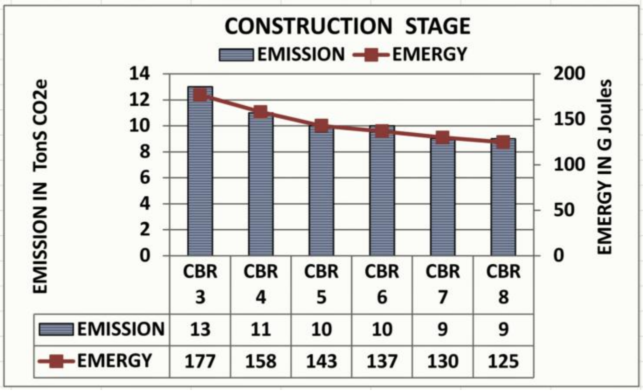

Fig. 15: Energy consumption and the emission construction stage.

The above four chart shows that, in all process involved in the construction of flexible pavement, the CBR value of the subgrade shows major impact in the total emission and energy consumption.

D. Social Carbon Cost

It is the total damage caused to the atmosphere in terms of dollar value , when one ton of CO_2 is released. Ricke.K et al. [23] estimated the social cost of CO_2 in India as $86 per ton of CO_2. Accordingly the estimated social cost of CO_2 for various values of CBR is tabulated.

Table 7 Social cost of CO_2 in construction of 1km flexible pavement of 7 m width with varying CBR from 3 to 8

Process	CBR 3	CBR 4	CBR 5	CBR 6	CBR 7	CBR8
Production of Material	$2,494	$2,236	$2,064	$1,978	$1,892	$1,806
Processing of Materials	$9,890	$8,514	$7,396	$7,052	$6,708	$6,364
Transportation	$3,268	$2,924	$2,666	$2,580	$2,408	$2,322
Execution at Site	$1,118	$946	$860	$860	$774	$774
Total Social Cost	$16,770	$14,620	$12,986	$12,470	$11,782	$11,266

The above table shows the social cost of CO_2 for various subgrade strength. It is seen that the cost increases with the decreasing values of CBR and cost is more at the stage of processing of materials compared with other stages.

IV.CONCLUSION AND RECOMMENDATION

A simple data tool LCAPAVE has been developed using the data collected from different journals, proceedings and Indian Standard Codes, and Standard Data Book to quantify the energy consumption and the emission of global warming gases in construction of flexible pavement. The processes included in the tool are raw material acquisition, processing of materials, transportation and laying, rolling at site. And the output is the total energy consumption in each stage of construction in Joules and the corresponding emission in terms of CO_2 equivalent in tons. The result shows that the processing of material stage, that is mixing of base course mixes and sub base course mixes and asphalt mixes require more energy and correspondingly the emission is more compared to other processes. A case study has been carried out using the developed tool keeping all parameters of pavement as constant and varying the CBR values of the sub grade. From the study, the maximum energy consumption and emission of GHG resulted by the processing of raw materials into mixtures in mixing plant which produces asphalt mix and non-bituminous mixes. Both emergy and emission decreases with corresponding increment of CBR values of sub grade. Hence the CBR values of the subgrade plays an important role in the life cycle of assessment of the construction of bituminous road. Therefore it may be concluded that the sub grade CBR values may be increased by adding suitable admixture or any other soil stabilisation methods, to reduce the energy consumption and GHG emission . The model developed here gives energy and emission as output for flexible pavement from stage of material acquisition stage upto construction stage. The model may be extended for maintenance of road and emission due to movement of traffic, street lighting for the entire design life of the pavement.

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