Research Article

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Carbon Footprint Estimation of Highway Construction Materials

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ABSTRACT

In India, there is an ever-increasing demand for enhancing the road network to cater to the requirements of the growing population. Greenhouse gas emissions from the road construction and rehabilitation process have a massive impact on the environment and global warming. A suitable tool to calculate, monitor and mitigate such carbon emissions is yet to be made. The objective of this research study was to develop an Excel tool, specifically tailored for the Indian construction environment – 'Carbon Footprint Estimation Tool for Highway Constructions' to estimate the carbon equivalent emission from the material used in highway construction. This tool aids in monitoring and comparing carbon equivalent emissions from different materials of different layers for both rigid and flexible pavements.

Keywords: Carbon emission; Carbon dioxide equivalent; Carbon footprint; Fly ash; Reclaimed asphaltic concrete.

1. INTRODUCTION

In this rapidly growing world, humans are more inclined towards the built environment rather than the natural environment. High-rise buildings, multiplexes, shopping malls, roads and highways are the basic amenities of the built environment. As the population increases the requirement of these amenities will also increase. Any establishment produces a large amount of Green House Gases (GHG) which emanates from materials, construction process, maintenance, operation, and demolition. For example, materials like aggregate have some self-embodied energy and some GHG emitted during mining by equipment, shorting machines and from the vehicles that transport them to the site. All the GHG emissions taking place in these processes account for the aggregate total GHG emission. The Paris Agreement was made within the United Nations Framework Convention on Climate Change (UNFCCC), dealing with GHG Emissions, mitigation, adaptation, and finance, signed in 2016 by 189 parties. The Paris Agreement's long-term goal is to keep the global average temperature of this century well below 2 °C above pre-industrial levels and to pursue efforts to limit the increase to 1.5 °C, which will substantially reduce the environmental risk. According to the United Nations Emission Gap Report 2019, if we rely on current climate situations temperature can be expected to rise 3.2 °C by 2100; currently, the temperature has already increased to 1.1 °C. Still, there lies a chance to limit global temperature to 1.5 °C, for which the emission must drop rapidly to 25 Gt CO_2e by 2030 which is currently on track to reach 56 Gt CO_2e by 2030; to achieve this target, we have to reduce it by 7.6% every year between 2020 and 2030. To limit global warming below 2 °C by 2100, the emission output has to be contained within 40 Gt CO_2e by 2030.

The transportation sector is a key part of the built environment for the development of any region. For the construction and proper maintenance of the highways a large number of construction materials and machineries are required. In present days almost every construction material originates from natural sources such as cement, brick, aggregate, steel, wood, lime and gypsum; only a few construction materials are man-made like paint, plastic components, geotextiles, etc. For the running of machines, a large amount of fuel and lubricants are also required which are also extracted from the earth. All these materials and energy have some embodied carbon associated with them; the processes involved in the construction and maintenance of roads also emit GHG, contributing to global warming. This work has been done to calculate the total GHG emissions from the highway construction process. For this work, the construction project – 'Six laning of Handia Varanasi section of NH-2 in Uttar Pradesh, under NHDP Phase-V, on Hybrid Annuity mode' of National Highway Authority of India was chosen (from 713.146 km to 785.544 km); it is situated in the eastern part of Uttar Pradesh which starts from Prayagraj and ends at Varanasi.

2. OBJECTIVE AND SCOPE

In the Paris Agreement, India has pledged to reduce the emission intensity of its economy by 33-35% by 2030, compared to 2005 level. To achieve this aim to reduce carbon emission, proper measurement of the GHG emission is necessary from every sector like household, agriculture, waste, energy, industries, construction, transportation, etc. It is very much essential to identify all potential sources of direct and indirect CO_2 emission during the entire life cycle which is required to identify the major sources of emission and to provide mitigation of this global concern. In India, there is neither a proper methodology nor a compulsion to measure the GHG emissions during the construction and maintenance period of any road, which seems to be a lack of vision to reduce GHG emissions. This work was done to provide a methodology and a computer program tool for calculating the Carbon footprint of highway construction materials in India. This tool was developed as a part of the study to quantify the major GHG contributor components of highway construction like material production, earthwork, rigid pavement layers, flexible pavement layers, structure, etc. This tool was used to estimate the overall amount of GHG emission from cradle-to-gate in terms of $MtCO_2$ equivalent emission ($MtCO_2e$). The scope of the study incorporated: (i) Background, to understand the background of the works and their role in GHG emission, considering cradle-to-gate life cycle, Analysis method and definitions of the terms most widely used in this work (ii) Literature review to understand the contribution of previous works and various factors responsible for the calculation of carbon footprint (iii) Formulation and calculation of GHG emission as per Indian Standard and other specifications related to construction materials of every layer and stage of constructions (iv) Development of Microsoft Excel-based tool to estimate the GHG emission and provide output in terms of total carbon dioxide equivalent ($MtCO_2e$) for different pavement layers and structure (v) Assessment and estimation of different combination of construction materials and their relative effect on overall CO_2e.

3. BACKGROUND

This section contains a detailed explanation of important concepts, terms and techniques related to the calculation of carbon footprint.

3.1 CARBON FOOTPRINT

The carbon footprint is defined as the total amount of Green House Gas (GHG) emissions or CO_2 emissions caused by an individual, organization, product, building, country, event, etc. Carbon footprint estimation can be defined as a subset of Life Cycle Assessment. It includes direct emissions and indirect emissions (Shashwath *et al.* 2016).

Carbon footprint can also be called embodied carbon. Carbon footprint is usually measured in metric ton of CO_2 equivalent ($MtCO_2e$) or kilogram of CO_2 equivalent ($KgCO_2e$) per year.

3.2 CARBON DIOXIDE EQUIVALENT (CO_2e)

‘Carbon dioxide equivalent’, ‘CO_2e’, ‘CDE’, ‘CO_2eq’ or ‘CO_2equivalent’ all are the same term used to represent GHG in a single number. GHGs can be expressed as CO_2e by multiplying the amount of GHG by its Global warming potential (GWP) of Kyoto gases.

If 1 kg of nitrous oxide is emitted, this can be expressed as 298 kg of CO_2e (1kg of N_2O x 298 = 298 kg of CO_2e).

The following units are commonly used:

- The UN climate change panel (IPCC): $n\times10^9$ tonnes of CO_2 equivalent ($GtCO_2eq$).
- In industry: million metric tonnes of carbon dioxide equivalents (MMTCDE).
- For vehicles: g of carbon dioxide equivalents/km (gCDE/km).

3.3 LIFE CYCLE ANALYSIS

Life Cycle Analysis (LCA) or Life Cycle Assessment is a technique for assessing the environmental impact associated with all the stages of a product, process or service over its life cycle. Life cycle analysis in road construction and maintenance is still at an immature stage which needs to be broadly studied and a functional framework is needed (Yu, B. and Lu, Q., 2012).

An LCA study consists of 4 stages:

a) **Goal and Scope (Stage 1):** In this first stage, goal is to define how extensive a part of the product life cycle will be taken for assessment and what will be the serving of that assessment. This stage includes a description of the function of the system investigated, functional unit, approaches, limitations of the study, data required, key assumptions, impact assessment method, interpretation method and type of reporting.

b) **Inventory (Stage 2):** In this stage, data is collected and interpreted. Inventory analysis has to be done which describes materials and energy flows within the product system and its interface with the environment, raw materials and emissions to the environment.

c) **Impact Assessment (Stage 3):** In the impact assessment, a category-wise product or service is examined from an environmental viewpoint. There are four elements of impact assessment:

    - Selection of impact categories, category indicators and models.

- Assignment of impact assessment results.
- Calculating the category indicator results.
- Data quality analysis.

d) **Improvement Assessment (Stage 4):** In this stage results from impact assessment are analyzed concerning goal and scope definition. Conclusions and limitations of the project are presented and recommendations are provided based on the result analyzed to make the process, product or service more environment-friendly.

In short, the 'goal and scope' will define the study's boundaries and limitations. The 'inventory' contains a complete inventory and categorization of the various elements involved in the cycle, the 'impact assessment' defines and calculates the environmental impacts and the 'improvement assessment' is the root for enhancing the existing procedure.

3.4 LIFE CYCLE ANALYSIS VARIANTS

There are many variants of Life Cycle Assessment based on assessment boundary and the specific focus on any particular stage.

Some of the variants are:

a) **Cradle-to-Grave:** Cradle-to-grave is a complete life cycle assessment that starts from source extraction (cradle) to service phase and the final disposal phase (grave).

b) **Cradle-to-Gate:** Cradle-to-gate is an assessment of a partial life cycle from resource extraction (cradle) to the factory gate (before it is transported to the consumer) or completion of work. The service phase and end phase are omitted in this case.

c) **Cradle-to-Cradle:** Cradle-to-cradle is a closed-loop production type which is a kind of cradle-to-grave assessment where the disposal step is a recycling process. In this after the service life project/product/service, the recycling process produces new products which are either identical to the original or different.

3.5 SOURCE OF EMISSION

According to CO_2e sources, the World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD) divided the sources of emission into three categories/scopes, in its Greenhouse Gas Protocol, as shown in Fig. 1. (Harangozo *et al*. 2017).

a) **Direct Emission (Scope 1):** Direct emissions are the ones released from the sources which are the entity being inventoried. These are the emissions that happen on the site/office during the process such as from the fleet vehicles, the emissions from machines and plants, on-site construction activities, wood and gas burnt in mess and electricity used.

b) **Indirect Emission (Scope 2):** Indirect GHG emissions are the ones released during the manufacturing or processing of electricity. Electricity indirect GHG emission is based on the generation of electricity in a power plant. This entity is a part of the inventory of the project but it releases GHG outside the boundary of the workplace during production. The GHG protocol addresses only electricity; however, other energy sources can also be accumulated in this topic.

c) **Other Indirect Emissions (Scope 3):** It covers all other associated indirect emissions such as emissions during the extraction and processing of materials, fuels, water, waste, transportation and staff commuting (Wahid *et al.* 2019).

For the calculation of carbon footprint or life cycle assessment of any highway, embodied carbon or emission factor of every direct and indirect emission source must be known for which IPCC, ICE, CleanMetrics^{TM} and so many other organizations have published their lifecycle inventory database which includes the amount of GHG emission from various materials. These databases are generally based on European countries or global average. However, the emission factor is linked with material changes, climate change, road conditions, the process of manufacturing, etc.; hence, it varies in every country. In 2018, India submitted a second biennial update report to UNFCCC in which India included its own National Greenhouse gas inventory.

4. LITERATURE REVIEW

The extensive, but fragmented research on Life cycle assessment (LCA), carbon footprint calculation and their methodology has been carried out in various parts of the world. Asian Development Bank (ADB), working for the sustainable development of the Asian Countries published the methodology for calculating the carbon footprint of the roads in India. Their methodology focused on total life cycle CO_2 emission from road project, from material, road construction, maintenance and the operation to the end of the road. For this methodology, they have chosen 4 different types of Road projects from India, funded by themselves. In the four projects, *viz,* National Highway (128.3 km, existing 2 lanes, upgradation from 2 to 4 lanes type of work), State highway (123.0 km, existing 6 m width, construction of overlays widening and new construction type of work), State highway (40 km, existing 6 m width, widening, strengthening and maintenance of existing pavement type of work) and Rural road (5.8 km, 1 lane, new road construction type of work), the observed total amount of CO_2 (ton/km) produced was 74880.2, 22861.2, 1822.6, 1476.4 respectively.

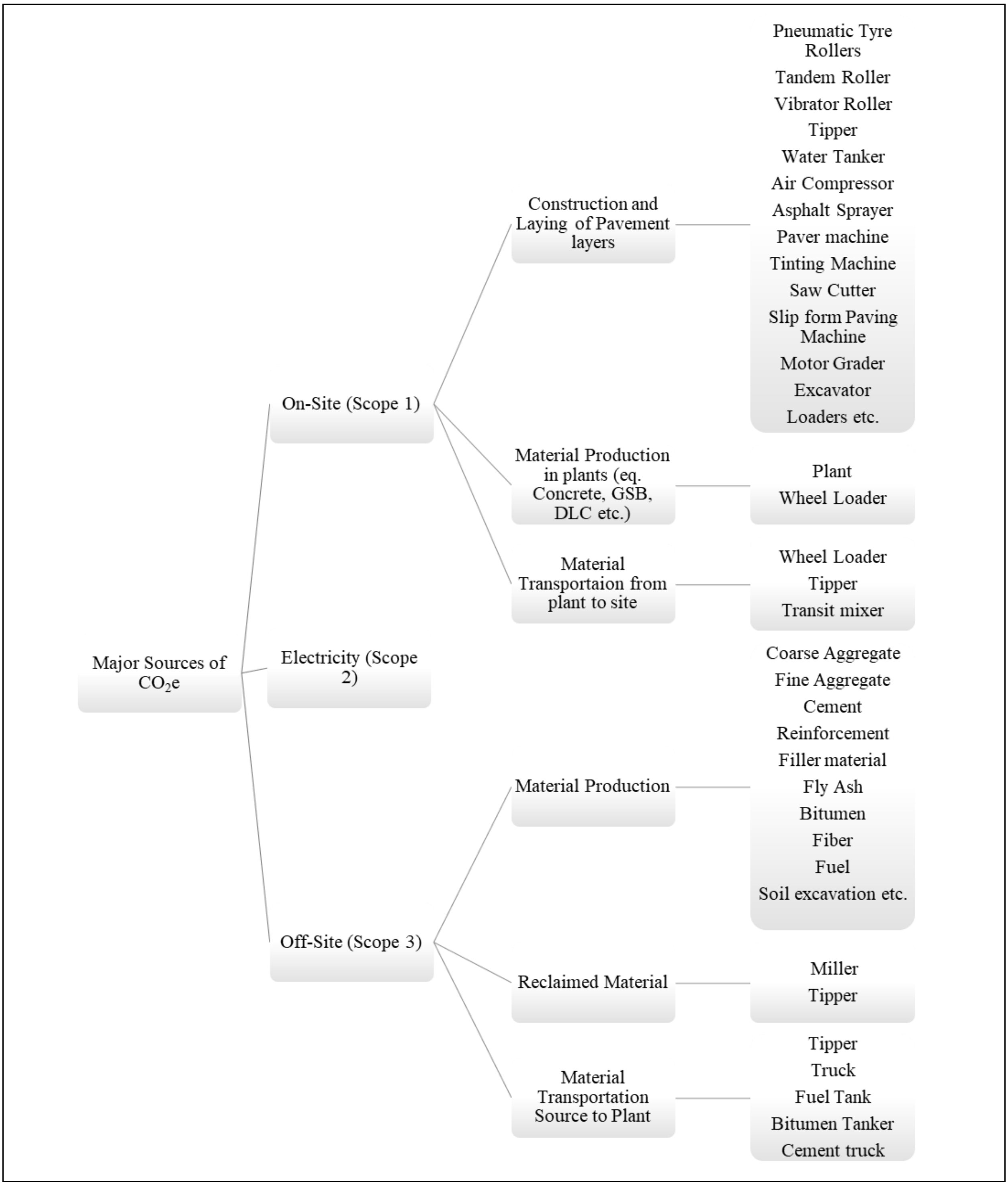


Fig. 1: Sources of CO_2 emission during highway construction

Ramachandra *et al.* (2015) studied GHG footprint of Indian cities and provided a methodology of calculating GHG emissions. They found that GHG footprint of Delhi, Greater Mumbai, Kolkata, Chennai, Greater Bangalore, Hyderabad and Ahmedabad are 38,633.2 Gg CO_2e, 22,783.08 Gg CO_2e, 14,812.10 Gg

CO_2e, 22,090.55 Gg CO_2e, 19,796.5 Gg CO_2e, 13,734.59 Gg CO_2e and 91,24.45 Gg CO_2e, respectively. The transportation sector is the major contributor to GHG footprint, contributing 7.9%, 7.9%, 17.66%, 20.25%, 12.31%, 11.38% and 22.41%, respectively.

Kumar and Goyal (2018) reviewed about the carbon emission from rigid and flexible pavement using a software - Vic Roads, and they found that in every case flexible pavement had far lower carbon emission than the rigid pavement. Overall, they found that emission from rigid pavements was 25% higher than flexible pavements, approximately.

Kar *et al.* (2020) did the estimation of GHG emission from rigid and flexible pavement using 'Calculator for Harmonized Assessment and Normalization of Greenhouse-gas Emissions for Roads (CHANGER)' software and analyzed that during construction of bituminous layers of flexible pavement. Bitumen was heated to 150-160 °C and the aggregates were heated to 170-180 °C, leading to higher GHG emission. So, alternative technology such as cold mix and warm mix technology should be adopted in road construction. During rigid pavement construction, concrete contributes about 96% of the total emissions so alternate options like fly ash or other low carbon materials could be used.

Wang *et al.* (2015) the studied the highway construction in the southwest part of China and proposed an empirical method to estimate the Carbon dioxide emission based on the four projects. They divided the whole construction project into three major stages: Material production, Material transportation and Onsite construction. Their results shows that the major CO_2e was generated from material production and the transportation of material generates least CO_2. They estimated emission density of road, bridge and tunnel as 5229 kg/m, 35,547 kg/m and 42,302 kg/m, respectively.

5. MATERIAL AND METHODS

The aim of this work was to develop a carbon footprint estimation tool, incorporating almost every section of highway construction which emits GHG's. A typical roadway construction project involves mainly five sections, *viz*, Road work, Structural work, Pipeline work, Miscellaneous work (barriers, road markings, painting work, signs and hoardings and other road furniture) and Energy (fuel, gas, electricity, etc.).

However, some exclusions and assumptions have been taken during the work; works during maintenance period, road furniture, lighting of road and transportation during outsourcing of raw material were not included. Single equipment and machineries used for various projects have long service time; hence, their impact was considered negligible. Fuel used in material production, construction and transportation equipment was taken from a single point of source, where the quantity of fuel was recorded; thus, the carbon emission from all the machinery calculated combined as total fuel. Carbon emissions and loss to the environment due to cutting of tree were not included in this work because it was compulsory to plant more than double that of the cut trees at the site. However, loss happened during the construction period was significant; but more than double the number of the trees planted will nullify the effect in a few years.

Table 1. A brief summary of some components used for the construction project (Cradle-to-Gate)

Material	Embodied Carbon	Unit
Water	0.000344	$MtCO_2e/kl$
Ordinary Portland cement	0.912	$MtCO_2e/mt$
Portland-pozzolana cement - fly ash based	0.6610488	
Average Admixture	1.666166667	
Steel bar and rod	2.29	$MtCO_2e/tcs$
Bitumen, Straight-run	0.1909	$MtCO_2e/mt$
Bitumen, Polymer-modified bitumen (PMB)	0.3263	
Bitumen Emulsion	0.2217	
GGBS	0.083	
Fly ash	0.008	
Sand and Aggregate, Virgin land won resources	0.00438435	
Recycled resources, no heat treatment	0.006095312	
Recycled resources, with heat treatment	0.118771667	
Recycled resources (Site won)	0	
RAP (recycled asphalt pavement)	0	
General soil/topsoil (Imported Soil)	0.024	

General soil (Site won soil/ muck shift)	0	
Geotextiles	2.54	
Polyester	2.7	
Steel RRS barrier single-sided	2.760	
Thermoplastic road marking	5.700	
Paint	3.760	
Electricity	0.82	
Bottled Gas	2.930	
Petrol	2.808	$MtCO_2e/kl$
Diesel	3.211	

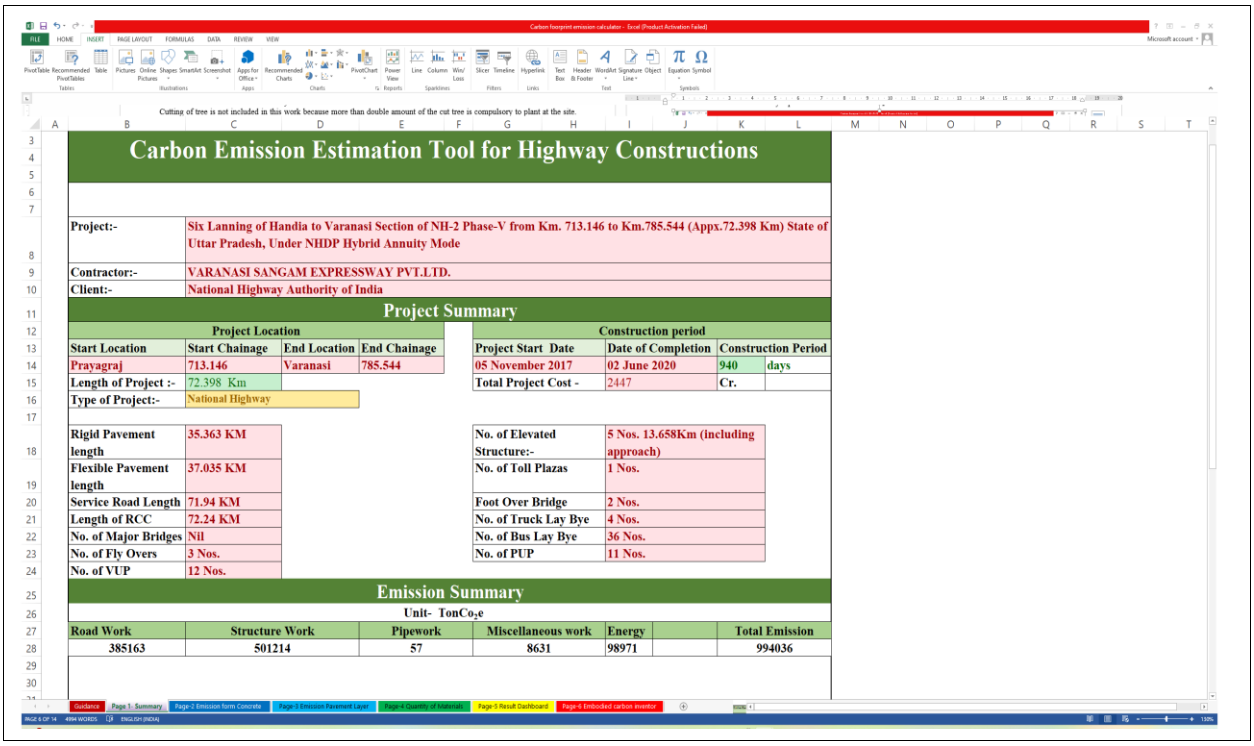


Fig. 2: Module 1 - Summary

The developed toolkit has five module which are described below:

A. Module 1 - Summary

Module 1 Summary, shown in Fig. 2, is an input page in which basic project details, project summary and emission summary are displayed. Data input in this input page are location, highway type, length of the project, construction duration, details of pavement and structures. Emission summary reported here have $MTCO_2e$ unit.

B. Module 2 - Emission from Concrete

As shown in Fig. 3, it is a Concrete carbon emission calculator which calculates the carbon emission from 1 m^3 concrete of different mix. In this page, users have to input the quantity of aggregates, cement, water, admixtures and water and in output, users will get output in $kgCO_2e/m^3$.

Input

Quantity of materials required to make 1 m^3 of concrete mix.

Output

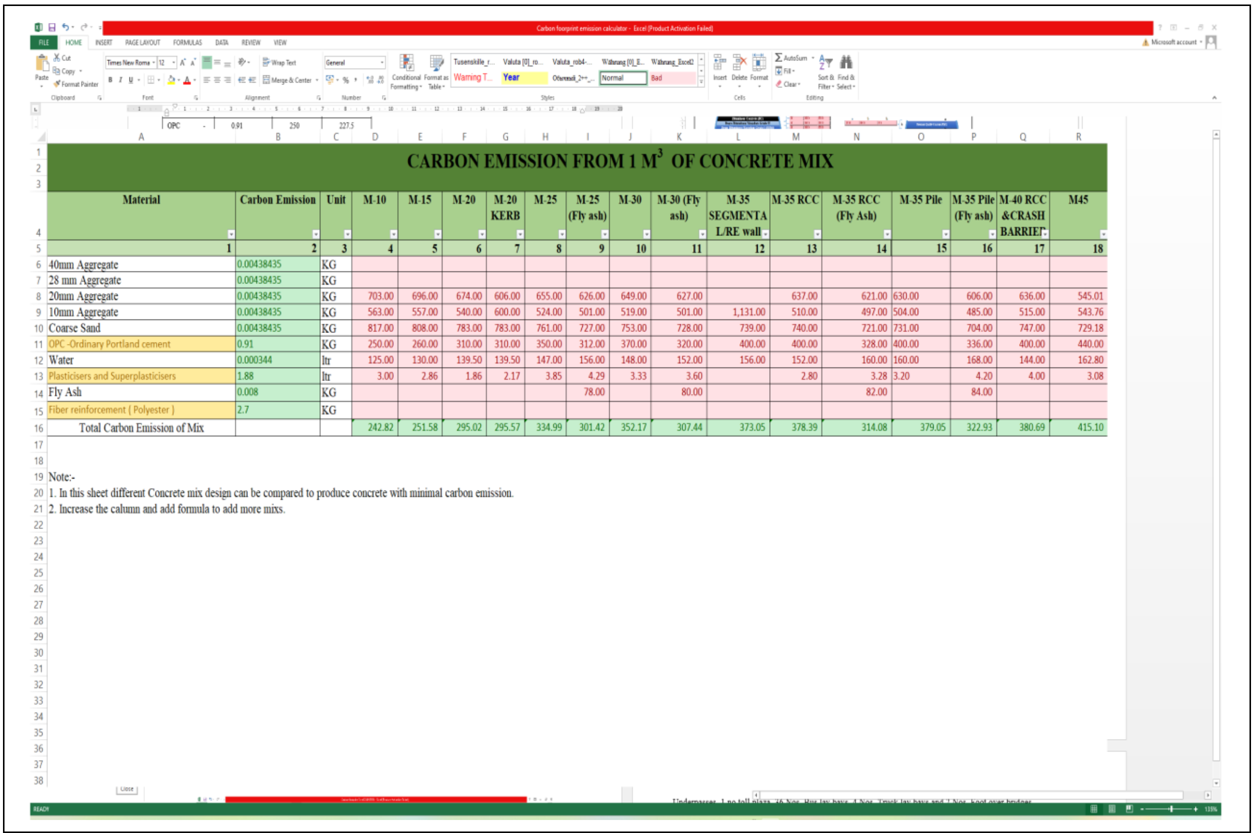
Total carbon emission = Σ (Carbon emission of material) x (Material Quantity)

C. Module 3 - Emission from pavement layers

This page (Fig. 4) deals with general pavement details, carbon emission from 1 m^3 of materials of different pavement layers of rigid and flexible pavement and carbon emission of selected km road length and lanes of materials of different pavement layers of rigid and flexible pavements.

Table 2: Example of Carbon Emission from 1 m^3 of M-10 grade concrete

Material	Carbon emission of material	Material Quantity for M-10	Carbon Emission
20 mm Aggregate	0.004384	703	3.082
10 mm Aggregate	0.0043843	563	2.46
Coarse Sand	0.0043843	817	3.582
OPC (Ordinary Portland Cement)	0.91	250	227.5
Water	0.00034	125	0.0425
Plasticizers and Super-plasticizers	1.88	3	5.64
Total Carbon Emission of the Mix			242.82 kgCO_2e/m^3



CARBON EMISSION FROM 1 M^3 OF CONCRETE MIX

Material	Carbon Emission	Unit	M-10	M-15	M-20	M-20 KERB	M-25	M-25 (Fly ash)	M-30	M-30 (Fly ash)	M-35 SEGMENTAL/RE wall	M-35 RCC	M-35 RCC (Fly Ash)	M-35 Pile	M-35 Pile (Fly ash)	M-40 RCC &CRASH BARRIER	M45
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
40mm Aggregate	0.00438435	KG															
28 mm Aggregate	0.00438435	KG															
20mm Aggregate	0.00438435	KG	703.00	696.00	674.00	606.00	655.00	626.00	649.00	627.00		637.00	621.00	630.00	606.00	636.00	545.01
10mm Aggregate	0.00438435	KG	563.00	557.00	540.00	600.00	524.00	501.00	519.00	501.00	1,131.00	510.00	497.00	504.00	485.00	515.00	543.76
Coarse Sand	0.00438435	KG	817.00	808.00	783.00	783.00	761.00	727.00	753.00	728.00	739.00	740.00	721.00	731.00	704.00	747.00	729.18
OPC -Ordinary Portland cement	0.91	KG	250.00	260.00	310.00	310.00	350.00	312.00	370.00	320.00	400.00	400.00	328.00	400.00	336.00	400.00	440.00
Water	0.000344	ltr	125.00	130.00	139.50	139.50	147.00	156.00	148.00	152.00	156.00	152.00	160.00	160.00	168.00	144.00	162.80
Plasticisers and Superplasticisers	1.88	ltr	3.00	2.86	1.86	2.17	3.85	4.29	3.33	3.60		2.80	3.28	3.20	4.20	4.00	3.08
Fly Ash	0.008	KG						78.00		80.00			82.00		84.00		
Fiber reinforcement (Polyester)	2.7	KG															
Total Carbon Emission of Mix			242.82	251.58	295.02	295.57	334.99	301.42	352.17	307.44	373.05	378.39	314.08	379.05	322.93	380.69	415.10

Note:-
1. In this sheet different Concrete mix design can be compared to produce concrete with minimal carbon emission.
2. Increase the calumn and add formula to add more mixs.

Fig. 3: Module 2 - Emission from Concrete

D. Module 4 - Quantity of Materials

The Module 4 - Quantity of Materials (Fig. 5), is an input field page in which all major materials used in road construction are listed; the users have to input the quantity of the material used in the project and it will give the complete carbon emission from road construction.

Input

Quantity of Materials / Total scope of work

Output

CO_2 emission = Total scope of work x Embodied carbon/individual carbon emission

Total Carbon emission from road project = Σ CO_2 emission

Embodied carbon/individual carbon emission represented in **Error! Reference source not found.** (ICE DB V3, 2019; Tata Steel, 2017; GOI-MOP, 2018; BEIS, 2019).

E. Module 5 - Result Dashboard

Result dashboard is the 5th page of this tool, which comprises the results in the form of multiple charts and also compares the pavements. This page consists of a total of five charts, as depicted in Fig. 6.

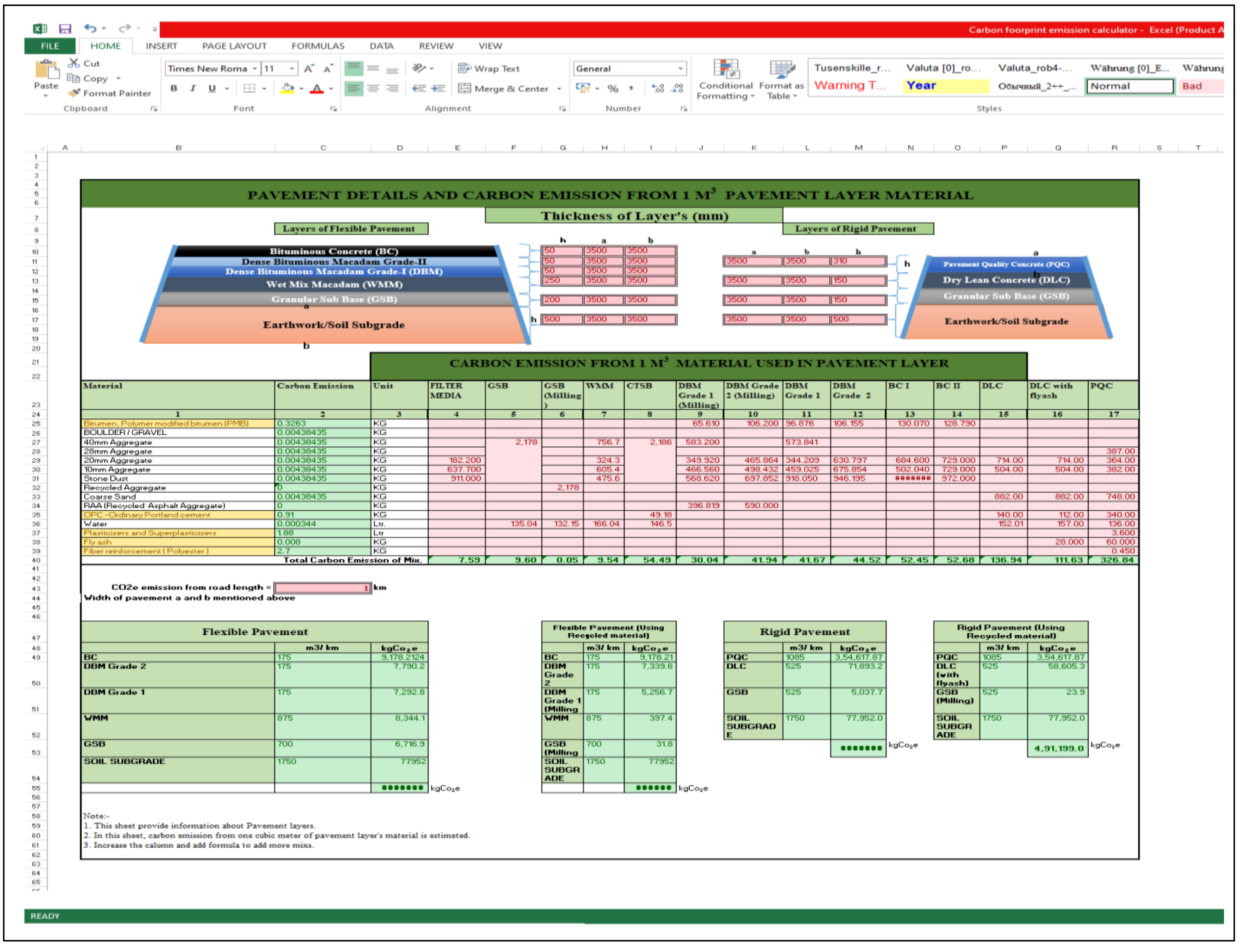


Fig. 4: Module 3 - Emission from Pavement layers

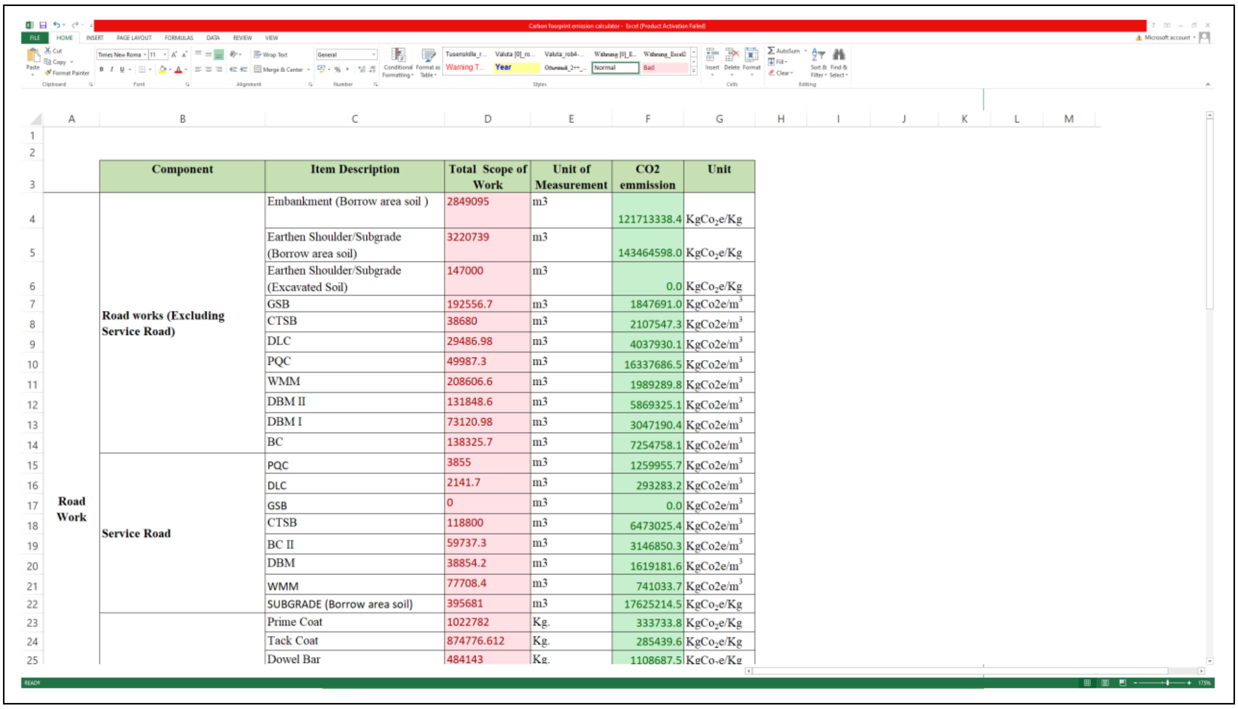


Fig. 5: Module 4 - Quantity of Materials

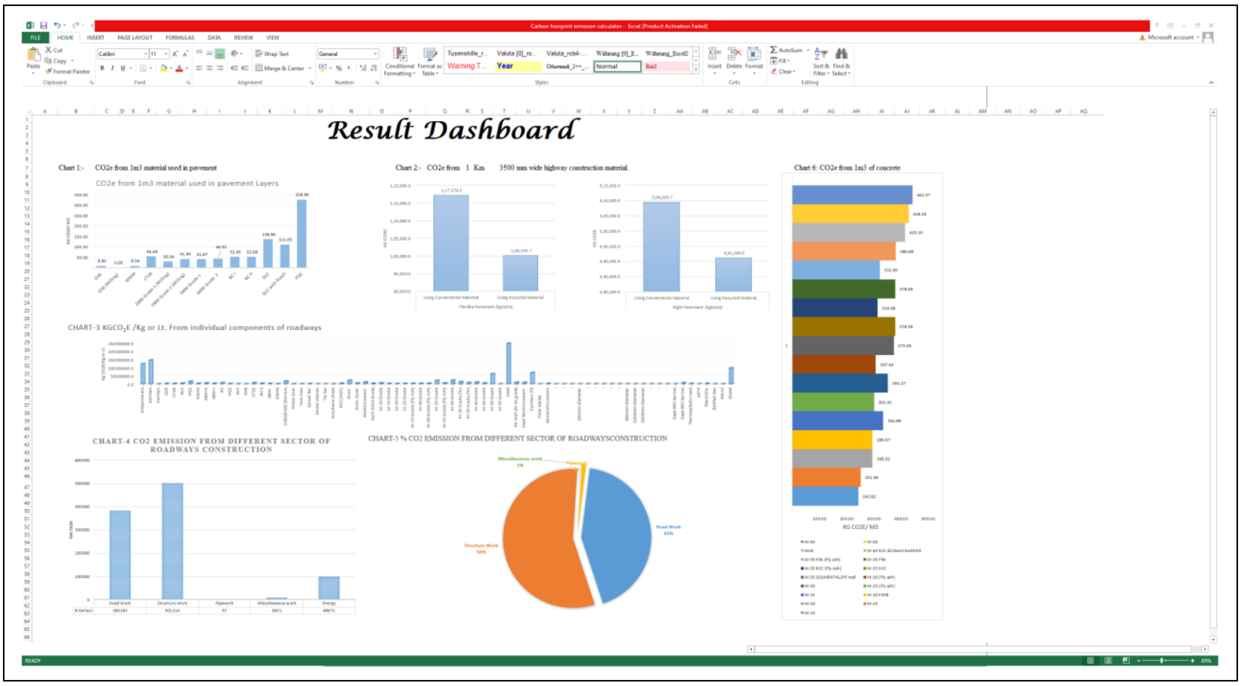


Fig. 6: Module 5 - Results Dashboard

Table 3. Quantity of material used in highway construction and their respective CO_2e

	Component	Item Description	Total Scope of Work	CO_2 Emission	Unit of Measurement	Unit
Road Work	Road works (excluding Service Road)	Embankment (Borrow area soil)	2849095	121713338.4	m^3	$kgCO_2e/kg$
		Earthen Shoulder/Subgrade (Borrow area soil)	3220739	143464598.0		
		Earthen Shoulder/Subgrade (Excavated Soil)	147000	0.0		
		GSB	192556.7	1847691.0		$kgCO_2e/m^3$
		CTSB	38680	2107547.3		
		DLC	29486.98	4037930.1		
		PQC	49987.3	16337686.5		
		WMM	208606.6	1989289.8		
		DBM II	131848.6	5869325.1		
		DBM I	73120.98	3047190.4		
		BC	138325.7	7254758.1		
	Service Road	PQC	3855	1259955.7		
		DLC	2141.7	293283.2		
		GSB	0	0.0		
		CTSB	118800	6473025.4		
		BC II	59737.3	3146850.3		
		DBM	38854.2	1619181.6		
		WMM	77708.4	741033.7		
		SUBGRADE (Borrow area soil)	395681	17625214.5		
	Other	Prime Coat	1022782	333733.8	kg	$kgCO_2e/kg$
		Tack Coat	874776.612	285439.6		
		Dowel Bar	484143	1108687.5		
		Dowel sleeves	854	2305.8		
		Tie bar	76088.8	174243.4		
		Polythene sheet	70196.4	189530.3		
	Road Side Drain	PCC (M15)	13031	3278308.6	m^3	
		Drain	64420	21580326.8		$kgCO_2e/m^3$
		Drain Cover	14400	4823916.6		
		Reinforcement	5123760	11733410.4		
	Kerb	Kerb (M20 Grade concrete)	9575	2824819.7		
Structure	Concrete work for Structures	M-10 Grade	26643	6469336.1		
		M-15 Grade	6301	1585190.9		
		M-20 Grade	4085	1205158.1		

		M-25 Grade	5665	1897742.2		
		M-25 Grade (Fly Ash)	8333	2511694.9		
		M-30 Grade	7410	2609606.7		
		M-30 Grade (Fly Ash)	10400	3197351.5		
		M-35 Grade	56935	21543609.4		
		M-35 Grade (Fly Ash)	18360	5766440.1		
		M-35 Grade (Segmental)	60659	22628985.5		
		M-35 Grade (for piling)	35434	13431181.6		
		M-35 Grade (for piling and FlyAsh)	24562	7931750.2		
		M-40 Grade	29780	11336979.0		
		M-45 Grade	12573	5219013.7		
		M-50 Grade	142106	60855473.0		
		M-55 Grade	356	157484.1		
	Reinforcement for Structure	Steel	106672904.3	244280950.7	kg	$kgCO_2e/kg$
	RE WALL	RE Wall (M-35 grade concrete)	26435.4	9861789.4	m^3	$kgCO_2e/m^3$
		Steel Reinforcement	3873975	8871402.8	kg	$kgCO_2e/kg$
		Earthern Fill	1528800	68098867.2	m^3	
		Filter Media	7930.7	60185.1		$kgCO_2e/m^3$
		Georeinforcement	666930	1694002.2	kg	
Pipework	Pipe work (HDPE Plastic)	-	0	0.0	m	$kgCO_2e/kg$
		-	0	0.0		
		-	0	0.0		
	Pipe work (PVC)	150mm diameter	3500	35782.1		
		-	0	0.0		
		-	0	0.0		
	Plastic pipework (Polypropylene)	-	0	0.0		
		-	0	0.0		
		-	0	0.0		
	Precast Concrete Circular Pipework	900 mm diameter	58	9167.7		
		1200 mm diameter	32	7997.2		
		1500 mm diameter	12	3836.3		
	Iron Pipework	-	10	0.0		
		-	0	0.0		
		-	0	0.0		
Miscellaneous work	Steel barrier	Steel RRS barrier single-sided	1286	79115.2		
	Steel barrier	Steel RRS barrier double-sided	69988	6865150.9		
	Road markings	Thermoplastic road marking	288000	1641600.0	kg	
	Paint	paint	10000	45120.0	l	
Energy	Electricity	Electricity	2925000	2398500.0	kWh	$kgCO_2e/Kwh$
	Bottled Gas	Bottled Gas	94000	275378.6	kg	$kgCO_2e/kg$
	Petrol	Petrol	112000	314446.7	l	$kgCO_2e/l$
	Diesel	Diesel	29890000	95982768.0		
			Total CO_2e	994035.7		tCO_2e

6. CASE STUDY

The tool was used to estimate the carbon footprint of flexible pavement, rigid pavement, structure and road furniture. This tool is also compatible to calculate the carbon emission of different concrete mix designs and layers considering the specifications of Ministry of Road Transport and Highways (MoRTH). For the study, a section of National Highway No. 2 (old) have been selected starting from the place Handia, Prayagraj district, Uttar Pradesh and ends at Rajatalab, Varanasi district, Uttar Pradesh. The versatility of this project is that it uses advanced construction techniques like pre-cast structures, RE walls, advanced machinery, and used recycled aggregate. The cost of the project is Rs. 2447 crores for the 72.64 km stretch of Project Highway - Six laning with paved shoulder configuration including 71.94 km service road, 5 elevated structures, 3 flyovers, 12 vehicular underpasses, 11 pedestrian/cattle underpasses, 1 toll plaza, 36 bus lay bays, 4 truck lay bays and 2 foot over bridges.

The quantities mentioned in Table 3 were consumed in every component and component-wise CO_2 emission generated were presented in the table.

7. RESULT AND DISCUSSION

The results drawn from the case study are explained below:

It was observed that with an increase in the grade of concrete, CO_2 emission also increases (as shown in Fig. 7), but it can be relatively decreased with the use of some recycled material or waste material. In this project, fly ash is used in some mix designs resulting in lesser emissions.

If we use fly ash as the partial replacement of cement in M25, M30, M35 and M35 (Pile concrete) grade of concrete, then the reduction in carbon emission was found to be 10.02%, 12.70%, 16.99%, 14.80% respectively.

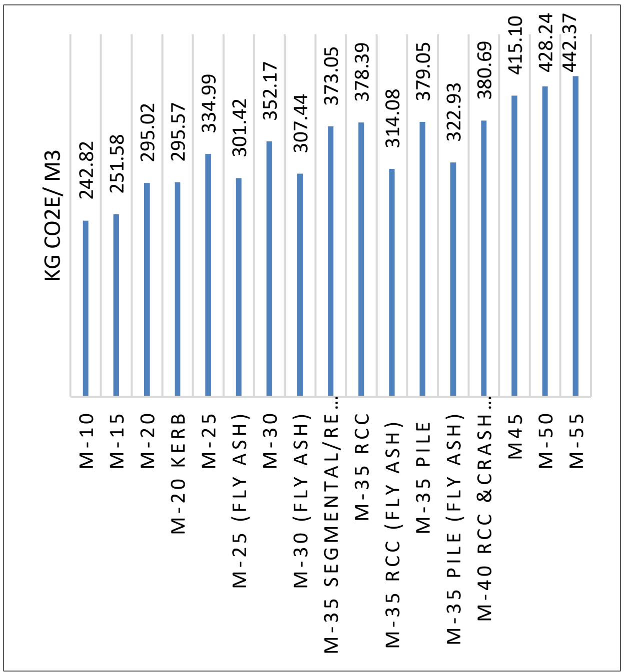


Fig. 7: Carbon emission from unit quantity of concrete

From Fig. 8 it was visible that the pavement material made using partial incorporation of recycled material (milling material) and fly ash have less emissions than conventional natural materials. In Table 4, it was shown that if milling materials (RAP/RAC) or fly ash used in the place of natural aggregate and cement in GSB, DBM 1, DBM 2 and DLC, then 99.47%, 27.9%, 5.8% and 18.48% less carbon emission takes place, respectively.

From the results of pavement material, CO_2 emissions from the rigid and flexible pavements can be compared for the same traffic; in the same way, carbon emission from rigid pavement made using virgin ingredient and using partial incorporation of recycled and waste materials can be compared.

It was found that during construction phase the materials used in rigid pavement makes 334.45% more carbon emission than flexible pavement for the same alignment. However, from the studied literatures it was observed that cradle-to-grave CO_2 emission of rigid pavement is less than flexible pavement.

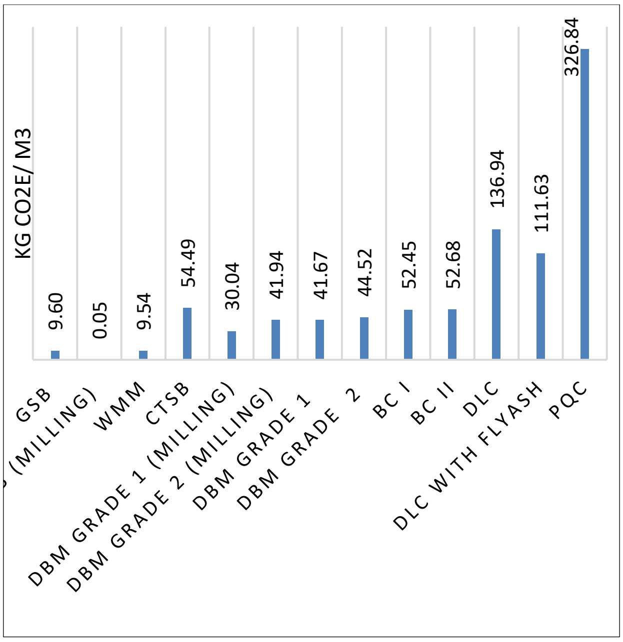


Fig. 8: Carbon emission from 1 m³ material used in pavement

To reduce the carbon emission from pavements, recycled or waste materials can be used which provides the equivalent strength. Results obtained from the tool for Flexible pavement (Table 4 and 5) and Rigid pavement (Table 6 and 7) and graphically shown in Figures 9 and 10 respectively, reveal that if the pavement was made using partial incorporation of recycled or waste materials as a replacement material the carbon emission can be by reduced 14.6% and 3.6% for Flexible and Rigid pavements, respectively.

Table 4. CO_2e in per km/lane from Flexible pavement using virgin material

Flexible pavement		
	m^3/ km	$kgCO_2e$
BC	175	9,178.2
DBM Grade 2	175	7,790.2
DBM Grade 1	175	7,292.8
WMM	875	8,344.1
GSB	700	6,716.9
SOIL SUBGRADE	1750	77952
		1,17,274.2

Table 5. CO_2e in per km/lane from Flexible pavement using Partial replacement of recycled material

Flexible Pavement (Using partial replacement of recycled material)		
	m^3/km	$kgCO_2e$
BC	175	9,178.21
DBM Grade 2 (Milling)	175	7,339.6
DBM Grade 1 (Milling)	175	5,256.7
WMM	875	397.4
GSB (Milling)	700	31.8
SOIL SUBGRADE	1750	77952
		1,00,155.7

Table 6. CO_2e in per km/lane from Rigid pavement using virgin material

Rigid Pavement		
	m^3/ km	$kgCO_2e$
PQC	1085	3,54,617.87
DLC	525	71,893.2
GSB	525	5,037.7
SOIL SUBGRADE	1750	77,952.0
		5,09,500.7

Table 7. CO_2e in per km/lane from Rigid pavement using partial replacement of recycled material

Rigid Pavement (Using Recycled material)		
	m^3/km	$kgCO_2e$
PQC	1085	3,54,617.87
DLC (with flyash)	525	58,605.3
GSB (Milling)	525	23.9
SOIL SUBGRADE	1750	77,952.0
		4,91,199.0

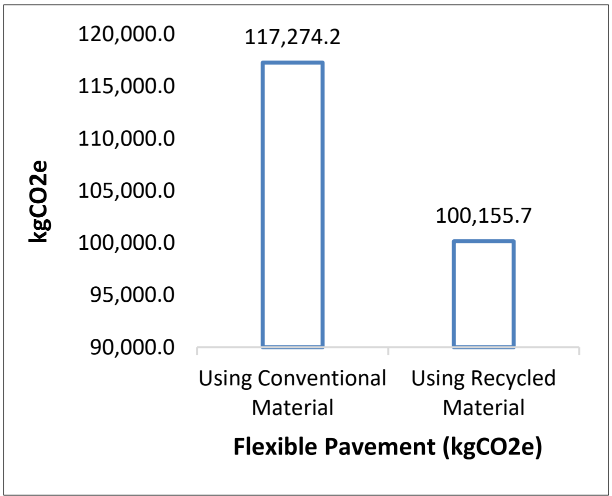


Fig. 9: Comparison of CO_2 emission from Flexible pavement made using conventional material and recycled material

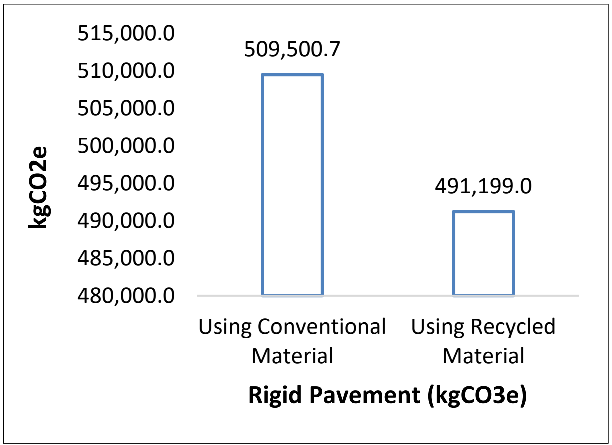


Fig. 10: Comparison of CO_2 emission from Rigid pavement made using conventional material and recycled material

8. CONCLUSION

This study proposed an empirical method to measure the Carbon footprints and to calculate Carbon dioxide emission using an MS Excel-based tool. In this study, based on the highway construction project in Uttar Pradesh state of India, the CO_2e emission from the materials used in the project and for transportation and construction phase, overall electricity and fuel consumed were taken into consideration. In this tool, CO_2e from all grades of concrete, materials used in highway construction and also each layer of rigid as well as flexible pavements were calculated separately.

Based on the data available from construction site, it was observed that from overall construction of project ‘Six Lanning of Handia - Varanasi section of NH-2 from 713+146 km to 785+544 km in the state of Uttar Pradesh’, the total emission from highway construction was found to be a total of 994035.7 $MtCO_2e$, in which road work, structural work, pipework, other miscellaneous work and energy contributes to 385163 $MtCO_2e$, 501214 $MtCO_2e$, 57 $TonCO_2e$, 8631 $MtCO_2e$ and 98971 $MtCO_2e$, respectively. This study also compared the CO_2e from different pavement types (flexible and rigid pavements and found that the materials used in rigid pavement makes 334.45% more carbon emission than the flexible pavement and it was also calculated that for sustainability, if the pavement was made using partial incorporation of recycled or waste materials as a replacement material, the carbon emission can be by reduced 14.6% and 3.6% for flexible and rigid pavements, respectively.

The tool and the results obtained from the study may be adopted for the Indian road construction industry for sustainable road construction.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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