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Potential Interventions for Reducing Carbon Footprint in Road Construction Projects- A Case of Pilot Green Highway Technologies in Gujarat, India

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***Abstract*—Green highway is a part of transportation planning and development system, designed with integration of certain green ecological functionalities like restoration of natural ecosystems, urban sprawl, population growth and public health with reference to standard systems such as Green Roads Rating System. Projects related to energy in highway development because of the infrastructure development that involve huge construction, operation and maintenance activities. One of the approaches to reduce carbon emission by applying green technologies around the world is the construction of green highways. The present study focuses on three green highway interventions related to materials & methods used for road construction in India on a pilot basis. Potential interventions for reducing the carbon footprint along with the other interventions like conservation of natural resources by reuse and recycling methods, usage of energy-efficient technology (WMA, Solar technology) and societal benefits (solid waste management and landscaping) in the project cycles were reviewed and discussed. A comparative study between existing technology and green technology in construction methodology was undertaken and calculated the carbon footprint using the emission factors and the fuel consumption. The change in carbon emissions between these two practices estimated as net carbon savings/credits have presented.**

Keywords*— Green highway technologies; energy efficiency; Carbon emissions; carbon credits, road construction material and methods.

I. INTRODUCTION

The Roads and Highways make a vital contribution to economic growth in the country by providing employment, social, health and educational services that provide an opportunity to fight against poverty. India has realized the importance of roads and highways and has been giving momentum to the faster development of highways to stimulate economic and social development in the country [1]. Construction of roads and subsequent use of toxic materials, pose an adverse impact on the environment in terms of loss of surrounding natural resources, natural ecosystems and human health. During construction high energy consumption leads to the generation of Carbon Footprint. Therefore, the restoration of the natural environment in the project area is necessary for considering environmental requirements throughout the stages of planning, designing, and execution. Road construction projects have to fulfill the criteria of sustainable development goals by providing socially desirable, ecologically feasible and economically viable solutions.

The term carbon footprint has been defined as the total amount of greenhouse gas emissions (CO, CH4, NOx, CFC, PFC, water vapour etc.) produced to support human activities over the life cycle of a product or activity. These carbon emissions are generally expressed as a single component that is carbon dioxide equivalent or CO2e that stands a unit for measuring other GHG emissions[1] [2]. The road transport sector is the leading mode of transport and the biggest emitter in the country with 90.1 percent followed by civil aviation sector (5.6 percent) and the railways and domestic water-borne navigation sectors (3.1 and 1.2 percent) of total carbon dioxide equivalent (CO2e) released respectively, as per estimations in 2014 in India [3].

International Road Federation (IRF) states that the effective ways of reducing GHG emissions in the transport sector by improving traffic flexibility and reduction of traffic congestion thus lower fuel consumption and an effective way of reducing greenhouse gas (GHG) emissions [4]. Other specific measures for reducing GHG emissions are also mentioned as enlarging the road network, replacing the crossroads with bridges, building bypasses, eliminating level crossings, effective traffic flow management etc. These require a plan in the design stage and identify the sources of

[1] Tons of Carbon dioxide equivalent - Carbon dioxide equivalent (CO2e) is a scale for measuring the climate effects of different gases, used to compare the emissions from various greenhouse gases based on their global warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential. For example, CO2e of 500 parts per million would reflect a mix of atmospheric gases which warm the earth as much as 500 parts per million of CO2 would warm it.

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carbon emissions being generated by the roads and highways construction activities. This requires the knowledge & vision of environmental science for planning in conservation of natural resources, at the same time engineering and technology is needed for designing stringent environmental policies required for its implementation to maintain the needs of the present without compromising the needs of future generations. Energy efficiency is the important agenda in highway projects to achieve sustainable development in this area. [5]

II. METHODOLOGY

The study objective is to estimate the carbon footprint of road construction projects and in comparison, with the pilot green highway construction concept to come up with a comprehensive understanding of the GHG emission reduction levels during construction and operation phases.

The following methodology adopted to estimate the carbon footprint for the roads and highways sector during the construction phase:

- ➢ Review and identification of potential interventions for reducing the carbon footprint;
- ➢ Collection of data regarding the project components like length of the project corridor under implementation, widening/construction options, material requirement, fuel consumption, energy usage etc. (i.e for green highway technologies)
- ➢ Estimation the carbon footprint for existing technology and green technology in terms of material and equipment usage and comparison with and without project scenario".

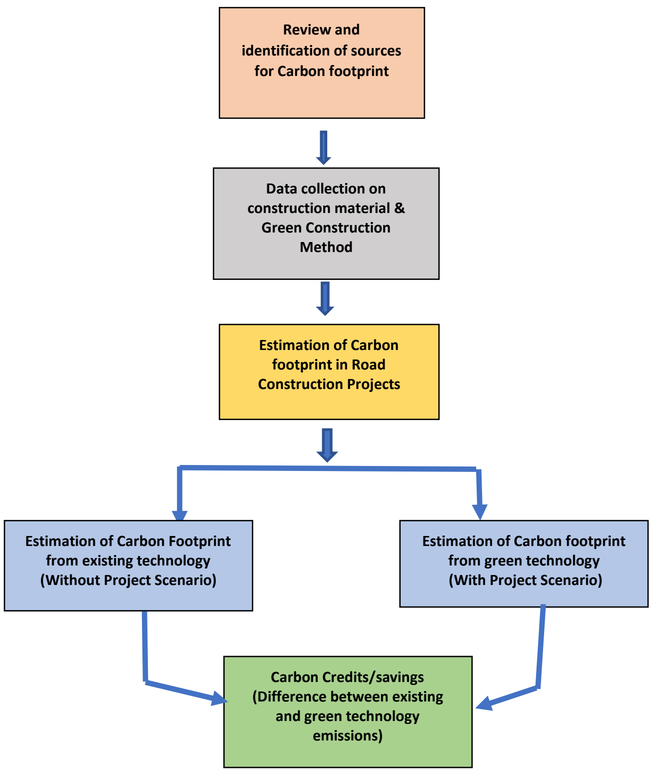

Fig 1: Methodology for Estimating Carbon footprint in road projects by applying Green Highway Technologies

A. *Review and Identification of Potential Interventions for minimizing the Carbon Footprint*

a. Before estimating the GHG emissions, it is vital to understand all possible sources of emissions during the project cycle. The possible sources of GHG emissions are divided into two types of emissions - direct, indirect or embodied emissions. Direct emissions are due to the combustion of fossil fuels like diesel, furnace oil, and light diesel oil etc. used for road construction sites in various construction machinery and vehicles. Indirect emissions are due to the production of construction material like extraction and mining of raw material, transportation and distribution. These indirect emissions can also be referred to as embodied emissions that are released at all the stages of the project cycle starting from construction to operation stage. Table 1 presents the possible interventions for reducing carbon footprint in road construction projects.

Table 1: Interventions for reducing Carbon footprint in Road construction projects

Project Cycle	Type of Activity	Interventions for reduction of GHG emissions
Planning and Design Phase	Alignment selection	Alignment selection that should minimize the removal of vegetation/trees and avoid nearby any ecological sensitive areas. Minimizations of removing vegetation/trees or planting trees along the road save the loss of carbon sequestration potential.
	Geometric design	Geometric design on reduction of fuel consumption & CO2 emissions
Project Construction Phase	Process of extraction/mining of raw material, transportation and distribution	Use of locally available material to reduce transport and fuel consumption, thereby reducing emissions. Efficient supply chain management to be followed. Efficient construction practices through reuses and recycles the excavated material.
	Construction vehicles at the site	Efficiency of equipment/vehicles by preventing maintenance/old vehicle usage. Use of latest engine technologies or with alternate fuel (bio and blended fuels) usage.
	Clearing and vegetation removal	Further minimize/avoid removal of vegetation/trees to save the Carbon sequestration potential lost by considering slight changes of the alignment according to the design speed during construction. Loss of carbon sequestration rate can compensate for planting trees at the site or somewhere else. However, in case wood/timber used for burning from which tree removal will be considered as direct GHG emissions.
	Setting up site offices/labour camps	Efficient site office designs (low-weight roof design, latest fabrication, use of recycled/low carbon intensity material etc. and rooftop ventilators to save electricity etc.) and efficient lighting technologies shall be used.
	Usage of Renewable energy	Decentralized renewable energy sources along the highway and retro reflective signals etc.

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Road operation/ Maintenance phase	Vehicles plying on the road	Optimization of vehicle miles travelled, improvements in the fuel economy and alternative vehicle technologies that emits less CO2. Speed control and traffic management and efficient toll collection management etc.
Green Technologies and Alternate material		
Planning, Construction and Operation stages	Use of waste material	Use of plastic waste or rubber in bitumen mix can reduce bitumen requirement and save CO_2 emissions. Increasing the use of fly ash in concrete mix can reduce carbon emissions. Appropriate use of construction demolition/debris etc.
	Use of alternate/recycled material	Usage of recycled asphalt through milling can very much help in reduction of carbon emissions and decreasing disposal in landfills, thereby reducing the carbon footprint and minimizing the environmental impact. Using WMA reduces fuel requirements for production of asphalt mix as less energy/heat is required in preparation. Green technologies like cold mix/warm mix technology to reduce CO2 emissions. Alternative construction materials (waste/recycled), glass grid pavements etc are the alternate/best practices.
	Prevention of Soil erosion/stabilization	Use of geo-synthetic technique can improve the soil stability and drainage capacity of pavement and aggressively promote this geo-synthetic technique. With this, routine maintenance of the road surface will be minimized. Hence minimize the fuel consumption and material requirement for regular maintenance.

Source: Draft Interim Report, TERI

The review of these studies provided a broader perspective to consider the developmental strategies for green highways are:

b. Various methods available for preservation of the ecosystem along the Roads and highways

c. Green integration and conservation practices make sure to minimize the generation of waste in construction.

d. Adopting green construction management practices can increase the energy efficiency domain etc.

B. Data collection and review of green highway technologies from Pilot study

The study aims to analyze and review pilot green highway technologies that have been implemented successfully in one of the highway projects in Gujarat, India. The review has also conducted green initiatives of best practices adopted as a pilot study for better planning and construction management to provide greener ways and estimation of the carbon footprint for road construction projects.

The following major components were implemented at the model/pilot corridor as follows:

- **Solar Street Lights**: Provision for standalone solar street lights (1355 numbers) with backup battery mounted Solar PV in the median for better visibility and free from tree canopy and at the road edges on both sides.
- **Warm Mix Asphalt**: Introducing Warm Mix Asphalt (WMA) for a 3km stretch, since it was a new construction;
- **Recycling of excavated material**: Recycling a minimum of 50% of the excavated pavement;
- **Solid waste management**: Across the green highway to have litter-free highway;
- **Landscaping** along the project corridor for better aesthetic appearance

The study methodology followed to observe the site condition, land and material procured for the green corridor based on Green Highway Partnership (GHP) principles [6] for better planning, design and construction management techniques.

The pilot green highway study was carried out by the Roads and Building Department, Government of Gujarat under the Gujarat State Highway Project -II. This study was planned during the design stage (for the stretch of 24 km, passes through two districts in Gujarat) by conducting screening, scoping studies, impact assessment, minimization, and management plans [7]. Additional measures studied and included in the implementation measures such as green initiatives (resource conservation/minimization methods, reuse of existing material, usage of energy efficient techniques etc.) were adopted under the guidance and with financial support of the World Bank based on principles of Green Highway Partnership program (GHP) to implement sustainability practices.

A separate budget was considered and included as part of implementing the green corridor by appointing an implementing agency/a facilitating agency to look after all the green initiatives and monitoring during the project implementation stage. The facilitating agency worked simultaneously during the construction of road works and suggested wherever inputs were required and worked closely coordinating with the contractor. The pictures below (Fig 6) have shown the implementation practices at the pilot corridor.

C. Estimating carbon footprint with the existing and pilot green technologies

Using the emission factors and the fuel consumption, the total GHG emissions in "with project" (with the green concept) and "without Project" (without green or existing/traditional concept) scenario calculated and the change in GHG emissions between "With Project" and "Without Project" estimated as the net GHG savings due to the project. This value is estimated in tons of Carbon dioxide equivalent (tCO2e) during the project construction period.

During the operation stage it can be expected that fuel consumption and reduction due to the improvement of road development components. The development of roads with broad perspectives leads to improved traffic flexibility and reduction of traffic congestion, thus lowering the fuel consumption and GHG emission reductions in the transport sector.

III. RESULTS AND DISCUSSIONS

Analysis of the effective green technology on carbon emissions reductions during the construction stage was carried out to identify the reduction of GHG emissions. The following figures in the subsequent paragraphs present the change in the amount of material usage and reduction of carbon emissions when applying green technology. Carbon emissions from existing technology (without project) and green technology (with project) gained by multiplying material consumption with emission reduction. Usage of solar lights substitute to the normal street lights gained the reduction of electricity consumption and emissions reductions as well. Carbon emission is also calculated through carbon sequestration rate by applying landscape provisions and tree transplantation. Detailed description of each component and the reduction of carbon emissions are as follows:

D. Warm Mix Asaphalt (WMA)

WMA technology was used for a 3 km stretch on a pilot basis on the surface of a green highway stretch. Most road constructions have bituminous surfaces using naturally available road aggregates and bitumen at very high temperatures to produce hot mix asphalt (HMA). The production of HMA mix designs along with available road aggregates, plastic components from recycled bottles & waste polymers seem to be an acceptable option to reuse tons of waste materials. But heating of bitumen to very high temperatures is linked to environmental degradation due to air pollution on account of increase in emission of gases into the atmosphere. Specifying the above, low energy mixes such as warm mix asphalt (WMA) prepared and used at much lower temperatures than HMA, are being extensively used in western countries to minimize air pollution and energy consumption.

Production of WMA gives significantly lower temperatures between 100 to 140ºC as against HMA which produces at high temperatures between 150 to 170ºC. Usage of WMA reduces the fuel-saving (energy consumption) by 30 % and emissions reduction by 46% (reduction of CO_2 by 30% and dust generation by 50-60% (source: Evotherm@WMA). With this green initiative, the estimated total carbon credits of about 300.819 MT of CO_2 for a 3 km stretch using WMA.

Total Carbon Credits= Total fuel consumption for the production of WMA X emission factor X quantity of aggregate

The Fig 2 presents with and without a project scenario of carbon emissions and the total carbon credits on usage of WMA during the project construction period.

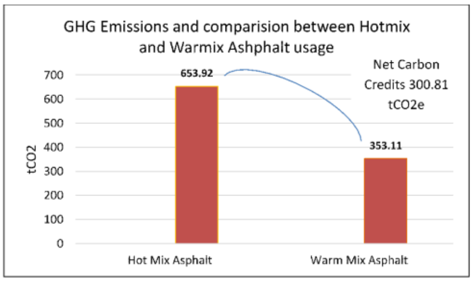

Fig 2 With (WMA) and Without (HMA) project and GHG Emissions scenario

E. Solar Lights

Conventional Standalone solar street lights options proposed including setting up on rooftops (Grid connected SPV system) and independent battery backup system. Total 1355 solar LED street lights proposed and installed at the corridor. With this initiative, calculated carbon credits are 639.18 MT of CO2e. The Fig 3 presents project techniques along with without project sources and the difference between these two with the reduction of carbon emission.

Carbon Credits = power consumption per kWh/per year X emission factor per kWh X total solar LED street lights

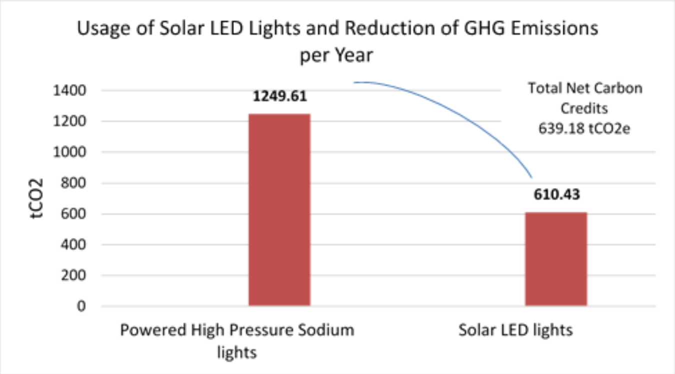

Fig 3 With (Solar Lights) and Without (HPS Lights) project and GHG Emissions scenario

F. Recyled Material

Excavated pavement (with a minimum of 50% of excavated pavement bituminous material) material was suggested during the planning stage based on the quality of sub-grade material and recycled for the pavement and at the embankment areas. With the proposed green intervention of recycling of pavement, contractor/Concessionaires have adopted to excavate the entire pavement material that was reused (100%) with their new construction machinery/equipment such as Milling Machine, Soil stabilizer and Asphalt paver etc. A total 13.41 lakh tons of pavement materials was removed and used as recycling material at the embankment areas, pavement and also used as debris for laying of approach/village roads, where it does not meet the requirement. With the adoption of recycling of pavement with new machinery technology, transferring the required material from identified borrow areas or third-party agencies was reduced, thus fuel consumption was minimized.

With this green initiative, it is estimated and calculated that total carbon credits are 1,134,317 kg CO_2 as well as economic benefits achieved with the reduction of transportation trips and time. The Fig 4 presents the traditional methods (without project) and green technology (with project) scenario of procurement of BT and base material and saving of carbon credits. It clearly indicates that recycling and reusing is the most effective way to reduce carbon emissions and can achieve more carbon credits.

Reduction of fuel usage (liters) X emission factor = GHG emissions reduction/carbon credits

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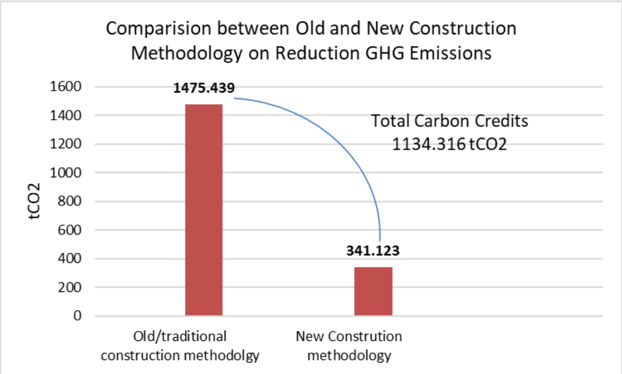

Fig 4: Comparison between New and Old Construction Methodology and Reduction of GHG emissions

G. *Solid Waste Management*

Solid Waste Management (SWM) along the highway proposed during the planning stage based on site-situation, limited services over the SWM practices. Five locations were chosen to implement SWM with collection and disposal of waste in consultation with the concerned local municipalities/village panchayats. At each selected location approximately 10kg per month of waste generation was estimated and calculated the GHG emission. Ten kilograms of waste generation release total CO2 as 8.25 tCO2e and CH4 emissions of about 6.5 tCO2e. Thus, effective SWM implementation at the selected locations along the highway. Overall reductions of Carbon dioxide and methane emissions by effective SWM was estimated that the total carbon credits calculated as CO2 equivalent (CO2e) is 14.75 tCO2e per month (Fig 5).

Total GHG emission-Methane (CH4) =quantity of solid waste generation/month (10kg) *emission factor Total GHG emission-Carbon dioxide (CO2) = quantity of solid waste generation/month (10kg) *emission factor

H. *Landscaping at the Corridor*

The Landscape along the corridor was developed at a limited stretch (for about 3 km road stretch) due to space constraint at the project site. Landscaping was done by planting vertical Creepers, Shrubs, Lawn and Seating arrangements etc. Carbon credits are calculated through Carbon Sequestration Rate (CSR)[2] per year and the number of creepers or shrubs used in the landscape area. With this initiative, total savings/carbon credits are 2.87 t CO2e (Fig 5) achieved as per calculation.

Carbon Sequestration Rate (CSR) X Number of Creepers, shrubs = total carbon credits/savings

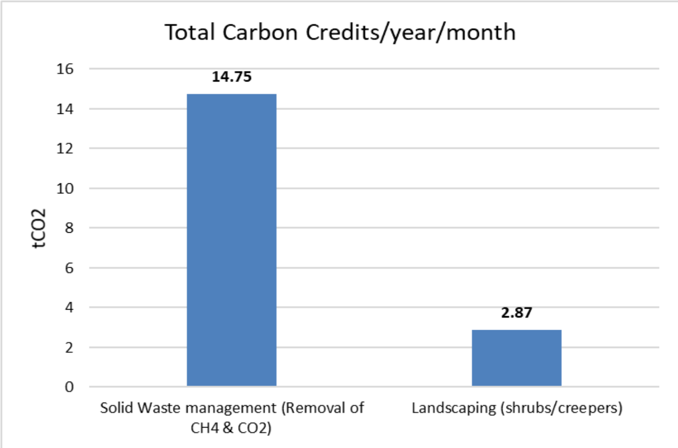

Fig 5: Carbon Credits achieved for Implementing SWM and Landscaping

Overall, the carbon credits estimated and achieved as a total of 2092.03 of tCO2e (Table 2) by applying the green highway interventions of WMA technology along with the recycling of pavement, solar street lights, landscaping and Solid waste management measures. Detailed estimation for each green component presented in Table 3 and the pictures captured during implementation of pilot green highway considerations are presented in Fig 6.

Table 2: Total Carbon Credits-Component wise

Green Components	Total Carbon Credits
Reuse of Pavement material	1134.316 tCO_2
WMA	300.81 tCO_2
Solar Street Lights	639.18 tCO_2
Landscape	2.87 tCO_2e
Solid Waste Management	14.75 tCO_2e
Total	**2092.03 tCO_2^e**

IV. CONCLUSION

This study estimated the reduction of carbon emissions when applying the green highway technologies related to construction materials and road construction under the heads of resource conservation (i.e low carbon technology, recycling and reuse of excavated material) and renewable resources (solar street lights) along with the societal benefits (i.e solid waste management, landscaping along the corridor). The analysis revealed that green highways technology reduced carbon emissions by 2092.03 tCO2e during the construction period. Carbon emissions calculated when the number of quantities of materials and the materials themselves used as recycling and reusing technology. Reduction in carbon emissions is driven by the change in construction work when the existing technology is replaced by green technology. Compared and analysis results of reduction may change depending on how the existing technologies compared with the green technologies are defined. The case in which a certain road section is designed by applying the existing technologies and that in

[2] CSR is the ratio of capturing and storing atmospheric carbon dioxide that will depend on the tree/plant size and the canopy.

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which a section is designed by applying a green technology (individually or in combination) has compared. Cost variance other than a reduction in carbon emissions should be taken into account since investment for technological development may be discouraged if the cost is too high. This study provides information on new green technologies applicable to designing and building new roads, and shares methodologies to researchers and policy-makers may consider when making decisions.

Table 3: GHG Estimation of Green Initiatives-Component wise

Warm Mix Asphalt:

1	Warm Mix Asphalt	Fuel (Diesel) consumption (lit)/MT	Emission of CO_2 Kg per litter*	Total CO_2 emission per MT	Total required quantity of aggregate for 3 km (MT) stretches	Total CO_2 emissi released for 3 kr aggregate usag
Without project	Hot Mix Asphalt	6.5	2.653	17.2445	37,920	653.92 MT of CO_2
With project	Warm Mix Asphalt	4.55	2.653	12.07115	37,920	457.74 MT of CO_2
	WMA reduces CO_2 by 46% (Source: Evotherm@WMA)					353.11 MT of CO_2
	Carbon credits/Savings					**300.89 MT of CO**

Solar Street Lights [8, 9]:

2	Solar Street lights (with LED bulbs)	power consumption for a single street light KWh/ year	Quantity of total lights	Emission of CO2 Kg per KWh	Total CO2 kg per /year for single light	Total CO2 emission released for 1355 street lights/year
Without project	High Pressure Sodium lights	1085	1355	0.85	922.25	1249.65 MT of CO_2
With project	Solar LED lights	530	1355	0.85	450.5	610.43 MT of CO_2
	Carbon credits/Savings				**471.75**	**639.22 MT of CO_2**

Source: http://www.cea.nic.in/reports/others/thermal/tpece/cdm_co2/user_guide_ver11.pdf

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Recycled Material [10]:

Traditional Method

Sr. No.	Description	Quantity (m3)	Diesel Usage (lit/cum/km-ton)	Total Diesel usage (liter)	CO_2 Emission* (Kg)
1	Excavation				
	BT Material (0.1m thick)	60,000	0.17	10,200	27,061
	Base Materials (0.5m thick)	300,000	0.15	45,000	119,385
	Soil (0.5m thick)	300,000	0.15	45,000	119,385
2	Transportation (5km/Ton)	1,341,000	0.34	455,940	1,209,609
				Total	**1475.439 MT**

2.653 Kg CO_2 emission per liter diesel consumption considered and this factor taken from
http://www.ghgprotocol.org/calculation-tools/alltools[9].

Revised methodology with new technology

Sr. No.	Description	Quantity (m3)	Diesel Usage (lit/cum/km-ton)	Total Diesel usage (liter)	CO_2 Emission* (Kg)
1	Excavation				
	BT Material (0.1m thick)	60,000	0.17	10,200	27,061
	Base Materials (0.3m thick)	180,000	0.125	22,500	59,693
	Soil (0.5m thick)	-	-	-	-
2	Transportation (lit/5km/Ton)	282,000	0.34	95,880	254,370
				Total	**341.123 MT**

Base material used 1, 80,000 m3 instead of the traditional method for base material and soil of a total 6,00,000 m3.
Diesel usage was almost same in two methods was followed.

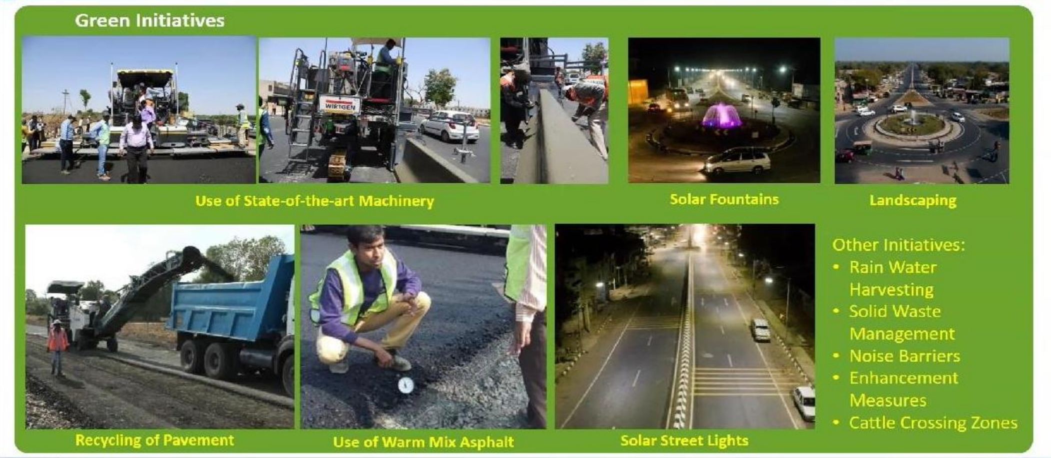
Total reduction of CO2 (the difference between traditional way of extracting material and adopting the recycling and reusing method
= 1,134,317kg

Solid Waste Management [12]:

4	Solid waste management (municipal waste)	Emission factor (gm/kg)	total waste generated (gm) at 5 locations	Emission of CH4 gm/kg/month	Total Carbon Sequestration (Reduction of Carbon emission)
with Project	5 locations (approx. 10kg of solid waste)-Methane (CH_4)	0.13	50000	6500	6.5
	5 locations (approx. 10kg of solid waste)-Carbon dioxide (CO_2)	0.165	50000	8250	8.25
	Total savings/Carbon credits			**14750**	**14.75 tCO_2e**

Landscaping at the Corridor [11]:

5	Land scaping (Carbon Sequestration Rate)	Rate of Carbon Sequestration	No. of Creepers/shrubs proposed	Total Carbon Sequestration (Reduction of Carbon emission)
With project	vertical creepers	0.18	4000	**720**
	Horizontal shrubs	0.43	5000	**2150**
	Total Savings/Carbon Credits			**2.87 tCO2e**



Picture Source: Author [a] study team, LEA Associates South Asia Pvt. Ltd (Design Consultant and Project Management Agency for Pilot study) and RKC Infrastructures (Contractor/Concessionaire for implementing the Green Initiatives in Gujarat)

Fig 6 Implementation practices on a pilot Study at the project corridor (North Gujarat, India)

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