The Energy and Resources Institute

सत्यमेव जयते

Ministry of Rural Development
Government of India

National Rural Roads Development Agency

Life Cycle Assessment of Hot Mix and Cold Mix Technologies for Construction and Maintenance of Rural Roads

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Prepared for

National Rural Roads Development Agency (NRRDA)

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List of Abbreviations

CAGR	Compound Annual Growth Rate
CBR	California Bearing Ratio
CPCB	Central Pollution Control Board
CRRI	Central Road Research Institute
CSIR	Council for Scientific and Industrial Research
GHG	Greenhouse Gas
GSB	Granular Sub Base
ILO	International Labour Organization
IOC	Indian Oil Corporation
IRC	Indian Road Congress
LCA	Life Cycle Assessment
MJ	Mega Joules
MoRD	Ministry of Rural Development
MoRTH	Ministry of Road Transport and Highways
MR	Motor Road
NAAQ	National Ambient Air Quality
NH	National Highway
NPV	Net Present Value
NQM	National Quality Monitor
NRRDA	National Rural Roads Development Agency
ODR	Other District Road
P&RD	Panchayat and Rural Development Department
PIU	Project Implementation Unit
PMGSY	Pradhan Mantri Gram Sadak Yojana
PWD	Public Works Department
PWRD	Public Works Road Department
RAP	Reclaimed Asphalt Pavement
RCC	Reinforced Cement Concrete
SQM	State Quality Monitor
SRRDA	State Rural Roads Development Agency
STA	State Technical Agency
SVNIT	Sardar Vallabhai National Institute of Technology
URRDA	Uttarakhand Rural Roads Development Agency
VOC	Volatile Organic Compounds
VR	Village Road

Executive Summary

India launched a comprehensive programme called Pradhan Mantri Gram Sadak Yojana (PMGSY) in April 2000 to connect all unconnected rural habitations with all-weather roads and to upgrade the existing rural roads. As of January 2017, more than 122,706 habitations have been connected, out of the targeted 183,599 habitations (MoRD, 2017); a total of 314,696 km of new rural roads have been completed and 170,021 km of rural road length upgraded. The rural roads programme in the country will continue in the coming years with proposed additions of about 68,446 km of new length and 32,098 km of up-gradation (as of January 2017) (MoRD, 2017).

While new road construction works are expected to bring several socio-economic benefits for the population, they also give rise to several negative externalities, such as emission of harmful pollutants and greenhouse gas (GHG) during construction and operations; consumption of scarce natural resources; adverse health impact on construction workers, labourers, and people at large; etc. It is important that these negative externalities during road construction and maintenance are minimised so as to ensure that the roads which are constructed are energy and resource efficient, environment-friendly and cost-effective. Also, these and other negative impacts of road construction and maintenance activities haven't received the desired policy focus, and adoption of clean construction materials and technologies as a result has lagged.

A major factor that contributes to emissions from road construction and maintenance activities is the technology used in laying the road. Conventionally, road construction in India has used hot mix technology, which is both energy and emissions intensive involving on-site heating to make the bitumen workable. Given that rural roads constitute the largest proportion (60.4%) of the total road network in India, it is necessary to introduce other advanced and cleaner technologies to control emissions and make rural roads construction and maintenance environmentally sustainable.

The study focuses on one such technology, that is, use of cold mix, which does not require on-site heating of bitumen – a necessary requirement in hot mix technology (Table 1). Another major advantage of this technology is that the cold mix pre-mix can be prepared under controlled conditions using modern technology, resulting in significant savings in energy use and emissions. However, in order to reach at par with other technologies, cold mix technology needs to be cost competitive not only in the initial construction stage but also over the life of the project where routine and periodic maintenance activities are undertaken.

Table 1 Comparison of hot mix and cold mix technology

Hot Mix Technology	Cold Mix Technology
Bitumen has to be heated on-site up to 150–160 °C to make it workable and temperature has to be maintained at all stages	On-site heating of bitumen is not required
Emission of air pollutants is more due to on-site heating/ burning of fuels	No heating/burning of fuels required, therefore causes less pollution
Difficult to lay wearing course in wet and cold climate resulting in possible delays in project completion	Wearing course can be constructed in all weather conditions using cold mix technology
Chances of accidents and harm to workers during work execution is high	Low chances of accidents and harm to workers

Source: *TERI analysis*

This study makes a comprehensive assessment of resource use, energy use, GHG emissions, pollution generation, project implementation experience, road repair and maintenance requirements, and cost of construction and maintenance associated with the use of both hot mix and cold mix technologies and presents a comparative analysis of both the technologies based on these parameters. It attempts to provide an understanding about the relative costs and benefits involved in terms of savings in energy consumption, GHG emissions, pollution generation, and life cycle costs, which expectedly can be used for making informed choices about the construction technologies to be used in rural road projects. Figure 1 provides an overview of the study framework.

Approach

In order to draw a comparison between hot mix and cold mix technologies, project level data on construction and maintenance-related activities was collected for a few sample projects in the states of Uttarakhand and Assam. These projects were selected in consultation with the National Rural Roads Development Agency (NRRDA) and relevant state authorities.

The study was conducted in two phases. In Phase 1, data was collected in two states – Assam and Uttarakhand. A total of eight rural road stretches were studied, of which four projects were under construction at the time of study and four projects had been completed at least five years prior and were under maintenance. Based on the results of Phase 1, it was realized that net present value (NPV) would be difficult to estimate for these projects, as none of the stretches had undergone periodic maintenance even once.

To overcome this difficulty, project selection criteria were revised in consultation with NRRDA and Assam Public Works Department and two new stretches were

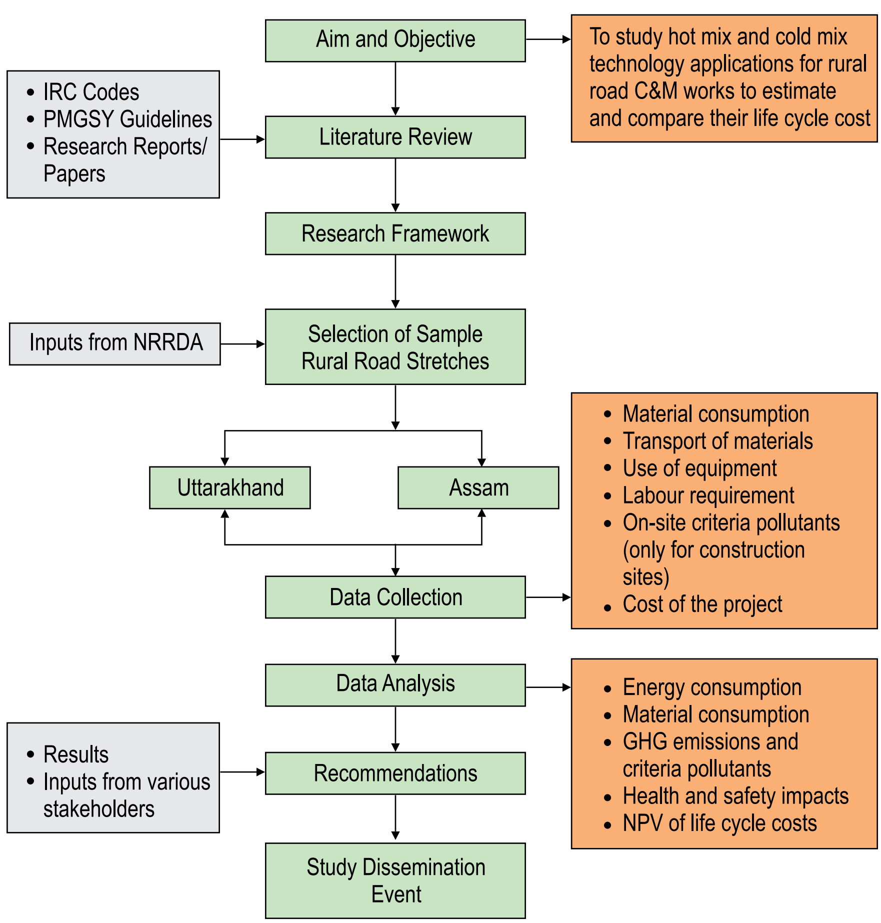


Figure 1 Study framework

selected for Phase 2. The revised criteria included the following:

- Sample rural road stretches should be located close to each other to minimize geographical/ terrain differences as well as differences in distance of transportation for construction materials;
- Project completion date for selected sample stretches should be in similar time period;
- Periodic maintenance should have been completed at least once on either rural road stretch in order to compare frequency of periodic maintenance required in hot mix and cold mix technology use

Key Results

In Phase 1 four rural road stretches were selected in each of the states, of which two stretches were under construction (one for hot mix and other for cold mix) and the other two under maintenance (one for hot mix and other for cold mix). Detailed data pertaining to energy use, material use, material transport, labour use, costs, etc. was collected for the selected projects and analysed in order to understand the differences in the two technologies. The key findings of the study have been discussed subsequently.

Uttarakhand

Table 2 below provides a summary of the results obtained from the study in the state of Uttarakhand.

Energy consumption

Rural road construction using hot mix technology consumed more energy than cold mix technology. This is true for both direct and indirect energy consumption and for projects under construction as well as under maintenance.

For projects under construction, total (direct and indirect) energy consumption was found to be 1.7 times more in hot mix project compared to cold mix project. Direct energy consumption on-site was nearly 10 times more for hot mix project as compared to cold mix project; this difference was due to higher consumption of fuel (timber) to heat bitumen at hot mix project sites. Indirect energy consumption was 1.2 times more for hot mix project compared to the cold mix project.

For construction of wearing course, total (direct and indirect) energy was higher in hot mix project than in cold mix project. The direct (on-site) energy consumption was nearly nine times higher in the case of hot mix project compared to cold mix project; however, indirect energy consumption was higher in the case of cold mix project due to increased transportation cost of construction materials over longer distance with higher number of trips compared to the project using hot mix technology. This reduced the gap in total energy consumption for the two projects.

For sample projects under maintenance, total (direct and indirect) energy consumption was 2.8 times

Table 2 Summary of results for sample projects in Uttarakhand

Assessment Parameter		Under Construction		Under Maintenance	
		Hot Mix	Cold Mix	Hot Mix	Cold Mix
Energy consumption	Total	Higher	-	Higher	-
	Direct	Higher	-	Higher	-
	Indirect	Higher	-	Higher	-
CO_2 emissions	Total	Higher	-	Higher	-
	Direct	Higher	-	Higher	-
	Indirect	Higher	-	Higher	-
Criteria pollutants		Higher	-	N.A.	N.A.
Material consumption		Higher	-	Higher	-

N.A.: Not measured at maintenance sites

Note: These results have been calculated on a per kilometre basis

Source: TERI analysis

higher in project using hot mix technology than in the project using cold mix technology. Direct (on-site) energy consumption was 11 times higher in hot mix project than in the cold mix project. Indirect energy consumption was 2.3 times higher in hot mix project than in the cold mix project. The use of biomass-based fuel (timber) for heating was the major cause of difference in on-site energy consumption. The use of coarse aggregate was much lower on a per kilometre basis for the project using cold mix, which brought down its indirect energy consumption as compared to the hot mix project.

Material consumption

For projects under construction, total material consumption was higher in the hot mix project than in the cold mix project. The hot mix project used higher amount of coarse aggregate, fine aggregate, and cement.

For construction of wearing course only, total material consumption on per kilometre basis was marginally higher in cold mix project as compared to the hot mix project. Usage of fine aggregate, essentially, was higher in cold mix project as compared to hot mix project.

For maintenance, total material consumption in the hot mix project was 2.5 times higher as compared to the cold mix project. The difference is because of higher use of coarse aggregate in the hot mix project

GHG emissions

In case of hot mix technology, more use of timber, coarse aggregate, and bitumen resulted in higher GHG emissions (both direct and indirect).

Total CO_2 emissions (direct and indirect) in hot mix project were found to be 2.3 times higher than in the cold mix project (projects under construction). CO_2 emissions due to direct (on-site) energy consumption were seven times higher in project using hot mix technology, while indirect CO_2 emissions were 1.7 times higher as compared to the cold mix project. In the construction of wearing course, total CO_2 emissions were 1.3 times higher in hot mix project. For maintenance, total (direct and indirect) CO_2 emissions in hot mix project were 3.5 times higher as compared to the cold mix project.

Criteria pollutants

Pollution monitoring at hot mix and cold mix sites was carried out in order to understand the differences in criteria pollution generation. The 24-hour average concentration of PM_{10} in both upstream and downstream directions at both construction sites in Uttarakhand were well within the National Ambient Air Quality (NAAQ) Standard PM_{10} concentration downstream of the construction site of project using hot mix technology increased due to use of biomass-based fuel.

The concentration of CO was below the detectable limit of the instrument at cold mix sites. The downwind concentrations of CO at construction sites with hot mix technology were significantly higher than the 8-hour average NAAQ Standard of 228 $\mu g/m^3$ in Uttarakhand.

The 24-hour ambient concentration of NO_x was recorded well below ($<6 \mu g/m^3$) the NAAQ Standard of 80 $\mu g/m^3$ at all construction sites. The volatile organic compounds (VOC) concentrations at all study sites were below the detectable limit of the instrument.

Assam

Table 3 provides a summary of the results of the study in the state of Assam.

Energy consumption

The survey results in Assam show total (direct and indirect) energy consumption to be higher in the hot mix project as compared to the cold mix project (in projects under construction). Direct (on-site) energy consumption was 1.2 times more in hot mix project as compared to the cold mix project due to use of kerosene for heating purposes. Further, use of large amount of cement for RCC works in earthwork and drainage in the hot mix project resulted in higher indirect energy consumption. In the cold mix project, higher number of trips for transport of materials resulted in higher indirect energy consumption.

For the construction of wearing course, total (direct and indirect) energy consumption was 1.2 times higher in cold mix project as compared to the hot mix project. This was mainly due to higher quantity of bitumen used in the cold mix project, which

Table 3 Summary of results for sample projects in Assam

Assessment Parameter		Under Construction		Under Maintenance	
		Hot Mix	Cold Mix	Hot Mix	Cold Mix
Energy consumption	Total	Higher	-	Higher	-
	Direct	Higher	-	Higher	-
	Indirect	Higher	-	Higher	-
CO_2 emissions	Total	Higher	-	Higher	-
	Direct	Higher	-	Higher	-
	Indirect	Higher	-	Higher	-
Criteria pollutants		Higher	-	N.A	N.A
Material consumption		Higher	-	Higher	-

N.A.: Not measured at maintenance sites

Note: These results have been calculated on a per kilometre basis

Source: TERI analysis

increased indirect energy consumption in the form of embodied energy. However, direct (on-site) energy consumption was higher for hot mix project due to burning of kerosene.

For maintenance, energy consumption in hot mix project was two times higher as compared to cold mix project. Higher amount of construction materials (cement, coarse aggregate) used in the project using hot mix technology results in higher indirect and direct energy consumption.

Material consumption

Total material consumption was slightly higher in project using hot mix technology as compared to cold mix technology in Assam (projects under construction). High use of coarse aggregate and cement in the project using hot mix technology accounted for this difference.

Material consumption for wearing course construction was marginally higher for hot mix project. The difference was on account of higher use of coarse aggregate in the hot mix project.

For maintenance projects, total material consumption in hot mix project was 1.6 times higher than in cold mix project because of higher use of soil and cement due to local conditions.

GHG emissions

Total CO_2 emissions in hot mix project were 1.4 times higher as compared to cold mix project (projects under construction). Use of kerosene resulted in higher direct (on-site) CO_2 emissions from the hot mix project as compared to the cold mix project. On the other hand, higher number of trips for transport of construction materials resulted in higher indirect CO_2 emissions in cold mix project.

In the construction of wearing course, total CO_2 emissions were 1.3 times higher in cold mix project as compared to hot mix project mainly due to high diesel consumption for transport of construction materials. However, direct (on-site) emissions were 1.7 times higher in hot mix project.

In projects under maintenance, total (direct and indirect) CO_2 emissions in project using hot mix were five times higher than emissions from the project using cold mix. This was mainly due to use of higher amount of soil and cement. High CO_2 emissions in transport of construction materials in cold mix project reduce the gap in total CO_2 emissions between hot mix and cold mix.

Criteria pollutants

Pollution monitoring at hot mix and cold mix sites was carried out in order to understand the differences in criteria pollution generation. The 24-hour average concentration of PM_{10} was higher than the NAAQ Standard at both the construction sites in Assam. The increase of PM_{10} concentration downstream of the construction site was higher with use of hot mix technology compared to that in cold mix. Use of kerosene during the use of hot mix technology resulted in higher PM_{10} concentration downstream compared to that with the cold mix technology.

The concentration of CO was below the detectable limit of the instrument at the cold mix sites. The downwind concentrations of CO at the construction sites with hot mix technology were significantly higher than the 8-hour average NAAQ Standard of 228 $\mu g/m^3$.

The 24-hour concentration of NOx was recorded well below (<6 $\mu g/m^3$) the NAAQ Standard of 80 $\mu g/m^3$ at all construction sites. The VOC concentrations at all study sites were below the detectable limit of the instrument.

Net Present Value

The NPV analysis was undertaken only for projects studied in Phase 2 in Assam due to reasons explained in approach section of this summary. The analysis of cost and expenditure data on the projects revealed that periodic maintenance would be an important determinant of life cycle costs savings between the two technologies. It was found that while the hot mix project had undergone periodic maintenance once, the cold mix project was yet to undertake periodic maintenance. But road condition was sufficiently robust so as to not require periodic maintenance for another year or so in the cold mix project.

As a result of additional periodic maintenance costs in the hot mix project, the NPV of the life cycle costs of the hot mix project were higher in hot mix project than in the cold mix project. The results are provided in Table 4.

Recommendations

Based on the results from the study and consultations with stakeholders at the workshop organized for dissemination of these results, following recommendations are being made for using cold mix technology for construction and maintenance of rural roads:

1. Cold mix technology needs to be incentivized to make it more cost competitive keeping in view the volatility in bitumen prices.
2. Economize on transport costs of cold mix technology by setting up more cold mix production facilities to prevent offset of on-site energy savings by indirect energy consumption due to transportation.
3. State agencies and project implementation units (PIU) should select cold mix technology

Table 4 NPV calculations for the sample rural road projects in Assam

	Year	Niz-Chilabandha to Langichuk	Dhekial to Sarubhogia
		Hot mix	Cold mix
Wearing course construction cost per kilometre (in Rs)		5,27,267	8,52,900
Routine maintenance cost per kilometre (in Rs)	2010	0	13,380
	2011	12,449	15,756
	2012	14,666	52,384
	2013	48,825	66,032
	2014	61,553	79,435
	2015	74,056	0
Periodic maintenance cost in hot mix project (Rs per kilometre)	2016	12,80,000	0
NPV		13,18,786	10,11,866

Source: TERI *analysis*

for projects by taking into consideration the following criteria

a. Need for extending working period for road construction in regions where working periods are restricted due to high rainfall or cold weather for most of the year. In such regions cold mix could be preferred technology due to its advantage of all-weather use

b. Availability of contractors, labour and engineers who have prior experience or training in using cold mix or are willing to work with new technologies

c. Testing facilities for assuring quality of cold mix bitumen/emulsion are accessible and reliable in the state

d. State Quality Monitors and National Quality Monitors have the capacity to carry out robust quality checks because they are aware and understand the implications on road surface quality of the use of various technologies including cold mix

e Incentives to engineers and officials for use of cold mix are available. For example, in Uttarakhand additional points are awarded to engineers of Assistant Engineer level and above in their Annual Confidential Report assessment for use of new technology, cold mix, waste materials, etc.[1]

f. If there is potential for savings in energy consumption during transportation due to availability of cold mix at feasible distances from the project site

Conclusion

This study is a preliminary attempt to understand the relative advantages and disadvantages of using hot mix and cold mix technology in construction and maintenance of rural roads. For a more comprehensive comparison, it is essential that cold mix technology is used in other projects in other states, as currently its use is restricted mostly to the North-Eastern region. More detailed studies/comparisons between the two technologies need to be carried out on parameters covered, but not limited to those considered in this study, in order to understand their relative costs and benefits. It is suggested that a firm policy directive on cold mix technology should evolve based on such research outcomes.

[1] As per official circular issued on May 6, 2017 by Uttarakhand PWD, http://pwd.uk.gov.in/pages/display/119-administrative

PART -1

STUDY METHODOLOGY, ANALYSIS, FINDINGS AND RECOMMENDATIONS

1 Introduction

1.1 Background

Realizing the importance of road connectivity for rapid and equitable socio-economic growth, India has been implementing several road development programmes at the national and state levels with an aim to augment and improve the road network in the country. At present, the road network spans to a length of about 5.2 million km,[1] of which rural roads form the largest share, that is, 3.2 million km (60.4%), whereas highways (national and state highways) account for 5%, district roads and other PWD roads 20%, and the remaining 14% comprise urban and project roads (Table 5).

Table 5 Type and length of different road categories in India (as on March31, 2015)

Road Type	Length of Roads (km)	Share (%)
National highways	79,116	1.51
State highways	1,69,227	3.23
Other public works department roads	10,66,747	20.39
Rural roads	31,59,639	60.39
Urban roads	4,46,238	8.53
Project roads	3,10,955	5.94
Total	52,31,922	100.00

Source: MoRTH, 2015

The country is committed to connect all rural habitations with a population of 500 and above in the plain areas and 250 and above in the hill states, tribal, and desert areas under the Pradhan Mantri Gram Sadak Yojana (PMGSY).[2] As of January 2017, more than 122,706 habitations have been connected of the target of 183,599 habitations. Further 314,696 km of new rural roads has been completed and 170,021 km of rural road length upgraded (MoRD, 2017). Based on available estimates, it is likely that 60,893 more habitations will be connected by rural roads and 170,021 km of new roads will be constructed and 32,098 km of rural roads will be upgraded in the next few years.

While new road construction works are expected to result in several socio-economic benefits for the population, they also give rise to several negative externalities, such as emission of harmful pollutants and greenhouse gas (GHG) emissions during road construction and road operations; consumption of scarce natural resources; harmful impact on health of the workers, labourers, and people at large; etc. It is important that these negative externalities during road construction and maintenance are reduced so as to ensure that benefits of providing road connectivity are energy and resource efficient, environment friendly, and cost-effective.

Traditionally, reducing negative externalities from road operations[3] has received significant attention in terms of policy action, but the externalities during road construction haven't received the desired focus and adoption of clean construction materials and technologies as a result has lagged. Road construction works can produce negative externalities (direct and indirect) on several accounts, such as

1. Use of energy and emission-intensive construction materials,
2. Use of energy and emission-intensive construction technologies and equipment,
3. Transport of construction materials/waste to and from construction site,

1 http://morth.nic.in/showfile.asp?lid=2445

2 Population size of habitations as per 2001 Census

3 Negative externalities such as vehicular pollution, accidents, and congestion due to vehicular movement

4. Delays in construction due to weather conditions,
5. Exposure of construction workers and population to harmful emissions,
6. Chances of accidents during construction work, etc.

A significant number of the above-listed negative externalities of road construction and maintenance works arise due to use of conventional construction materials and technologies, indicating the need to find substitutes for conventional materials and technologies in order to reduce the GHGs and other environmental and social impacts on account of road construction and maintenance works.

1.2 Rural Roads—Construction Technology

1.2.1 Hot mix

Developed in the year 1870, hot mix technology was fairly simple in those times having just drying, screening, proportioning, and mixing process (IRC: SP: 88-2010, 2010). With advancement in technology, these simple techniques improved with addition of aggregate bins, cold elevators, rotary dryers, hot elevators, bitumen tanks, and mixing platforms. It is the most extensively used technique for the production of bituminous aggregates.

Rural roads in India have conventionally been constructed using hot mix technology. Hot mix asphalt is a tried-and-tested road construction material, which meets several requirements of Indian road conditions and traffic loads. The conventional method of hot mix is a process in which the bitumen is heated up to 150–160 °C to make it workable. In this technology, it is extremely important to maintain the desired temperature at every stage. Failing to maintain these temperatures affects the durability of the pavement. High rainfall, high altitude, cold weather conditions, long distance between hot mix plant and project site, are some of the challenges faced during construction of pavements using this technology.

Hot mix technology also has significant impact in terms of on-site emissions, high requirements of energy to heat bitumen and aggregate to required temperature, exposure of construction workers to harmful emissions, etc., which all need to be minimized to preserve human and environmental health. Recently, due to the increase in awareness about climate change, the hot mix technology, due to its high energy consumption and high GHG emissions, has come into question (Indian Roads Congress, 2002).

1.2.2 Cold mix

Cold mix technology is an alternative to address the above-discussed shortcomings of hot mix technology. Cold mix is bituminous mixture containing unheated mineral aggregate, water and binder (bitumen emulsion) prepared by a suitable device like concrete mixer or cold mix plant or a modified hot mix plant. The technology has been developed by CSIR-CRRI. Cold Mix technology is an engineered mix design of tailor made cold mix bitumen binder, made suitable for available aggregates to derive durable bituminous surface based on zero pre-wetting of aggregates, workability, compatibility and setting time properties depending on equipment and climate (CSIR-CRRI, 2016) (Indian Roads Congress, 2014).

The technology came into existence in the early 1900s and its application, as a pavement, was first started in 1920s. In India, the use of cold mix first started in 1970s; by that time, the world had started using it in various fields of construction and maintenance of roads. In 1970, when India consumed only 20,000 tonnes, the whole world consumed about 12 million tonnes of cold mix bitumen (CSIR-CRRI and BitChem, 2013).

As of December 2016, 4,896.3 km of rural roads had been constructed using cold mix technology (National Rural Roads Development Agency [NRRDA], 2015). Most of the cold mix road length has been constructed in the north-eastern region with the highest length in Assam (Figure 2). So far, other states have accounted for only 10%, of which Odisha, Uttarakhand, and Karnataka are major users of cold mix technology for rural roads construction.

The increasing use of cold mix technology offers an opportunity to assess and compare the two available construction technologies for rural roads, that is, hot mix and cold mix in terms of their:

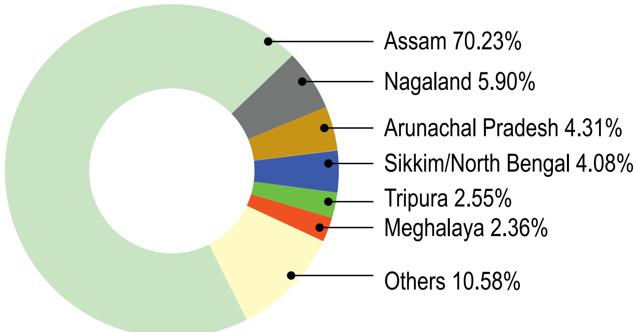


Figure 2 State-wise distribution of rural roads constructed using cold mix technology

Source: NRRDA

1. Energy requirements
2. Material requirements
3. Emissions generation (local pollution and GHG emissions)
4. Health impact
5. Project implementation (time required for construction works, weather conditions in which the two technologies can be used, labour force requirements, etc.)
6. Road repair and maintenance requirements
7. Cost of construction and maintenance

An assessment and comparison on the basis of the above-listed parameters will help in understanding the full life cycle cost of the two construction technologies and will provide useful policy insights into the technology/ies that should be promoted for construction and maintenance works in India. This study aims to carry out this analysis with an objective to create a scientific basis for selection and promotion of clean road construction and maintenance technologies for the rural roads sector.

1.3 Aim of the Study

It aimed to study hot mix and cold mix technology applications for rural roads' construction and maintenance works in India in order to estimate and compare their life cycle cost, energy consumption, GHG and criteria pollutants generation, material consumption, impact on health of construction workers and population, road maintenance requirements, and project implementation requirements.

1.3.1 Specific objectives of the study

For the full life cycle analysis of both hot mix and cold mix technology applications in rural roads, following steps were carried out:

1. Study and estimate the direct and indirect energy consumption for road construction and maintenance activities
2. Estimate the GHGs, specifically CO_2 emissions, emitted on account of construction and maintenance activities (direct and indirect emissions)
3. Measure the generation of criteria pollutants, such as PM_{10}, CO, NO_x, volatile organic compounds (VOC), etc., due to construction activities
4. Study health impact on construction workers near construction sites on account of construction activities
5. Study and estimate the resource/material consumption for construction and maintenance activities
6. Study and estimate the road maintenance requirements for the two technologies
7. Study the experience of project implementation in order to understand differences in the time required for construction works, weather conditions in which the two technologies can be used, labour force requirements, etc.
8. Study the costs incurred for construction and maintenance activities and estimate the net present value (NPV) of life cycle costs

1.4 Scope of Work

Figure 3 broadly summarizes the scope of the study.

A life cycle approach has been adopted to understand the differences in the two construction technologies. As shown in Figure 3, the scope of life cycle assessment (LCA) includes indirect energy consumption for production and extraction of materials used for construction and maintenance of roads. Additionally, energy used for transportation of these materials to the site has also been considered along with GHG emissions generated on account of this. During construction and maintenance

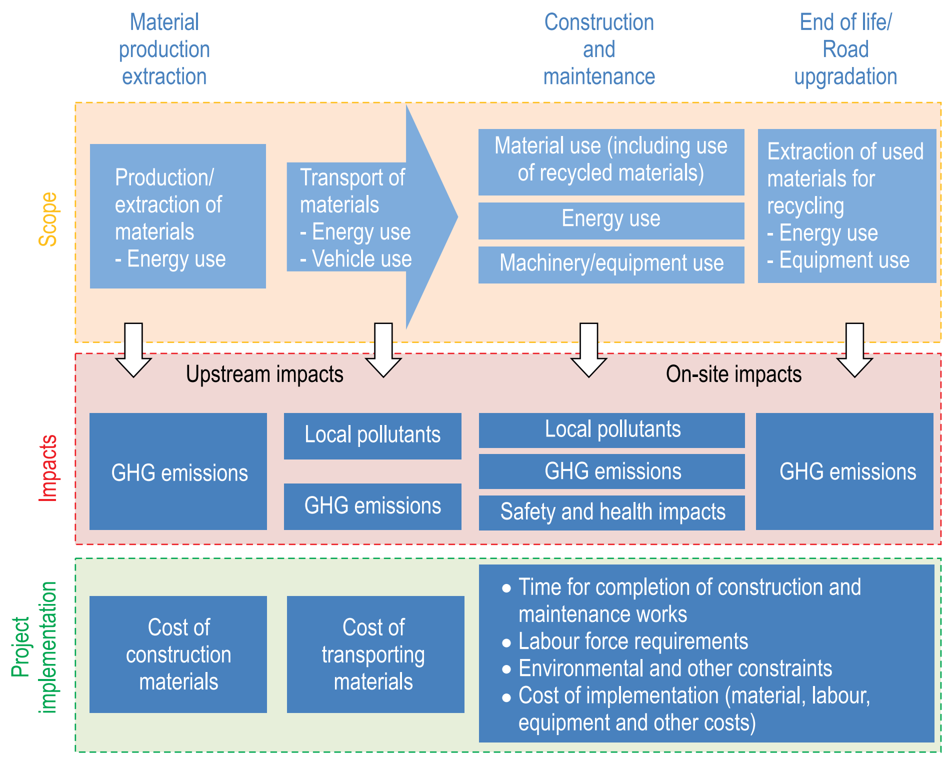


Figure 3 Scope of the study

phase, estimation of quantity of materials used for construction and maintenance has been included in the scope of LCA along with energy consumed for on-site construction works. Inclusion of all these stages helps in comparing the impact of the two construction technologies on life cycle basis. The specific approach and methodology adopted for the analysis is discussed in detail in the subsequent chapters.

2 Study Approach

A bottom-up approach was adopted to compare the two construction technologies, that is, hot mix and cold mix technology for construction and maintenance of rural roads. In this approach, comparable sample road stretches were selected and data was collected for these through detailed survey questionnaires to enable further analysis required for the study. The sample contained rural road stretches that represented different life stages of road construction and maintenance. Details of tasks involved in the study and the methodology/ies used to conduct these tasks are discussed in the following sections.

2.1 Tasks, Methodology, and Outcome

The key tasks carried out to achieve the objectives of the study are discussed along with the methodology that was adopted to perform the tasks and the outcomes from each task. Table 6 summarizes the key tasks, methodology, and outcomes.

2.1.1 Task 1: Development of broad research framework of the study

As part of Task 1, a detailed literature review was carried out to develop a research framework for the study. Indian Roads Congress (IRC) codes and PMGSY guidelines pertaining to rural roads' construction and maintenance and other research reports and papers were studied in order to understand the rural roads construction and maintenance practices in India. Based on this review, a broad research framework for the study was defined to outline the various components of life cycle of rural roads that were to be studied during the study. As part of Task 1, a detailed review of methods to assess various life cycle impacts was also carried out in order to identify the methodologies that could be adopted for data analysis in the study. The research framework and the identified methodologies were discussed with experts to seek their inputs and suggestions on improving the same. The data requirements were summarized in the form of questionnaires and data checklists that were used for data collection from sample sites. Part 2 of the report summarizes the work carried out as a part of this task and provides the key findings from the literature review and the questionnaires/data checklist used in the study.

2.1.2 Task 2: Selection of sample road stretches

This task involved selection of sample rural road stretches. The aim was to have a sample that included the roads under construction and maintenance for both the technologies.

2.1.2.1 Phase 1

It was aimed to select the road stretches in two different terrains, that is, hilly and plain/rolling terrain. Based on these criteria, a total of eight sample road stretches were needed, four roads stretches each for hot mix and cold mix representing roads under construction and under maintenance. The selection of road stretches was made in consultation with the National Rural Roads Development Agency (NRRDA); the selected road stretches were in Uttarakhand and Assam. It should be noted that the road stretches selected were very close to each other. This helped ensure that the environmental and geological conditions did not change considerably for a particular terrain, making it easier to compare the road stretches. The selected sample road stretches are listed in Table 7.

Table 6 Key tasks, methodology, and outcomes

Tasks	Methodology	Key Outcomes
Task 1: Development of broad research framework of the study	Literature review of similar studies Expert consultations	• Data requirements for the study were determined • Approach for NPV calculations was finalized
Task 2: Selection of sample road stretches	Development of criteria for selection of sample road stretches Inputs from NRRDA and experts	• Phase 1 – Eight projects were selected, four each in Assam and Uttarakhand • Out of four projects in each state, two were under construction and two were under maintenance • Phase 2 – Two projects were selected in Assam, of which one had completed periodic maintenance
Task 3: Primary data collection	Establishing contact with respective authorities/contractors Field visits for data collection	• Responses from all projects (Phase 1 and Phase 2) were received. Data on energy use, material consumption, use of equipment, transport of materials, project implementation details, etc. collected from contractors • Air quality was measured at each construction site • Climatic conditions and construction parameters for each project under construction were obtained
Task 4: Data analysis and report writing	Following estimates were done for all selected road stretches • Energy consumption • Material consumption • GHG emissions and criteria pollutants • Health impact • NPV of life cycle costs	• Detailed comparison of energy and environmental impact, resource consumption, health impact, and life cycle costs of the two construction technologies were carried out
Task 5: Study dissemination event	Organizing a workshop to disseminate study results	• Workshop attended by all stakeholders, including the NRRDA, was organized

Source: TERI *analysis*

Table 7 Selected sample rural road stretches in Phase 1

Terrain	State	Technology	Stretch
Under construction			
Hilly	Uttarakhand	Hot mix	Bajoon to Adhora MR (Stage 2)
		Cold mix	Petsal–Bamanswal–Kapkot MR
Plain/rolling	Assam	Hot mix	Ghoramari Buragaon to NH-52
		Cold mix	Ghogra TE to NH-52
Under maintenance			
Hilly	Uttarakhand	Hot mix	Daniya–Ara–Salphar MR
		Cold mix	Pahariyadhar to Surang MR
Plain/rolling	Assam	Hot mix	Gorehagi to Chalia
		Cold mix	Borpura to Rotuwa

Source: TERI *analysis*

2.1.2.2 Phase 2

Selection criteria were revised based on the results of Phase 1. New criteria included were:

- Projects to be in close proximity to each other to minimize terrain differences
- Projects having nearly same completion dates
- Periodic maintenance should have been completed at least once in either of the projects

Based on the above revision, projects mentioned in Table 8 were selected in Assam.

2.1.3 Task 3: Primary data collection

After selection of sample rural road stretches, the team visited these stretches and met the officials/ contractors in charge to collect detailed data on construction and maintenance-related activities, as identified in Task 1. The data primarily included information on construction and maintenance activities in terms of their energy use, material consumption, use of equipment, transport of materials, project implementation, and construction-related accidents. Additionally, the team also collected data on pollution levels during construction (at the construction sites) by measuring concentration of pollutants using pollution monitoring devices.

2.1.4 Task 4: Data analysis and report writing

The data collected for sample road stretches was analysed to carry out the following estimations for the two technologies.

- Energy consumption
- Material consumption
- GHG emissions and criteria pollutants
- Health impact
- NPV of life cycle costs

The estimates were compared for hot mix and cold mix technologies in order to understand the differences in the two technologies in terms of their energy and environmental impacts, resource consumption, health impact, and life cycle costs.

2.1.5 Task 5: Study dissemination event

A workshop was organized on August 18, 2017 to disseminate the findings of the study. An interactive session took place wherein results of the study were discussed in detail and relevant suggestions were given (refer to Annexures 9.6 and 9.7).

Table 8 Selected sample rural road stretches in Phase 2

Package No./Year of Sanction	Name of Road	Technology	Date of Completion	Periodic Maintenance Status
AS1972, 2006-07	Niz-chilabandha to Langichuk	Hot mix	28.02.2009	Periodic maintenance done in 2016/17
AS1973, 2006-07	Dhekial to Sarubhogia	Cold Mix	10.08.2009	Not done

Source: Assam PWD

3 Assessment Parameters and LCA

As stated earlier, LCA approach has been used in order to make a holistic comparison between the environmental, resource-use, and financial impact of cold mix technology vis-à-vis hot mix technology in construction of rural roads. LCA is a process-based 'cradle-to-grave' approach that can be defined as 'compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its lifecycle' (ISO 2009).

The LCA method is one of the most widely used methods to assess financial and environmental implications of any infrastructure project and its energy/carbon footprint (Gemchu, 2012; Guine'e, 2002; (ISO, 2009). There are various advantages in using this approach, especially in the case of road projects, such as:

1. LCA is claimed to be the best approach to calculate emission intensities of products and services by many academic and scientific studies (Gemchu, 2009)
2. Despite being data and time intensive, it systematically records and analyses various product/service-related parameters and enables an integrated assessment throughout its entire life cycle
3. Application of LCA method has been widely accepted across the world, especially to study road projects
4. It enables an end-to-end analysis of all components, raw materials, transportation, resource use, production process, and final disposal of the product/service

The following section discusses the parameters for which LCA of the selected hot mix and cold mix projects was carried out.

3.1 Assessment Parameters

3.1.1 Energy consumption and CO_2 emissions

3.1.1.1 Estimating energy consumption and CO_2 emissions

TERI has developed a comprehensive bottom-up methodology to estimate energy consumption (direct and indirect or 'embodied') and CO_2 emissions after extensive literature review and comparative analysis of various methodologies used to estimate carbon footprint of roads/highways. A list of the key Indian and international methodologies reviewed in this regard are provided in Annexure 9.1.

Two Indian studies, namely, '*Life cycle analysis of transport modes (2012)*' and '*Methodology for estimating carbon footprint of road projects, Case study: India (2010)*' have laid a comprehensive framework for estimating the carbon footprint of all three phases of road construction—construction, operation, and maintenance. The LCA framework drawn up by TERI (2012) is in line with ISO 14000 framework for carrying out LCA studies and incorporates international best practices mentioned therein. This framework has been used to estimate the energy consumption and CO_2 emissions on account of construction and maintenance activities. Figure 4 provides an overview of the construction and maintenance activities considered while estimating direct and indirect energy consumption/CO_2 emissions.

3.1.1.2 Direct energy consumption and CO_2 emissions

Road construction and maintenance involves direct consumption of energy which is required

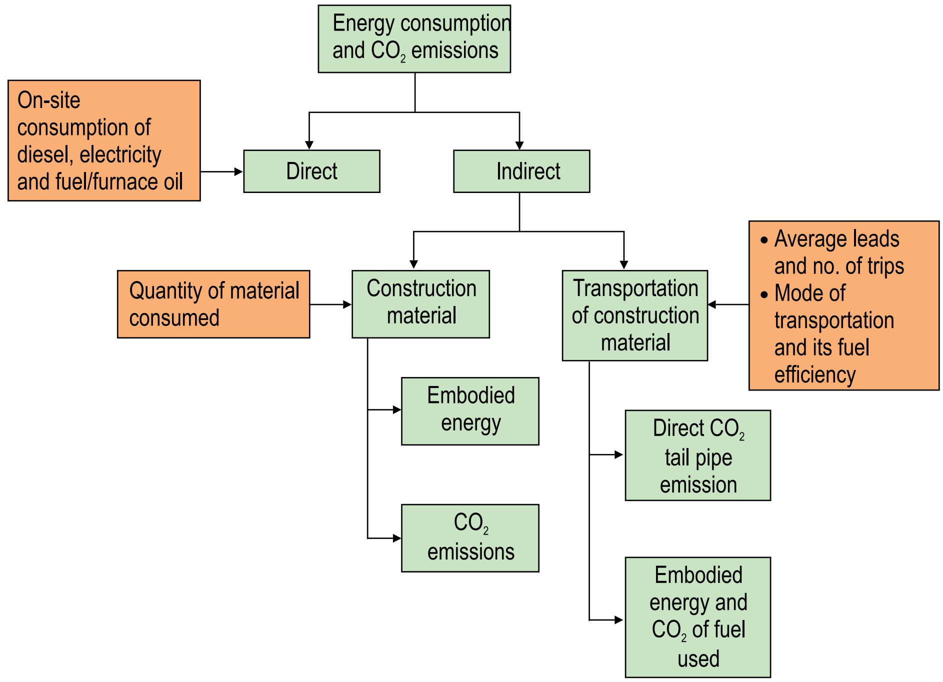


Figure 4 Calculation of direct and indirect energy consumption

Source: TERI analysis

to run construction machinery and equipment, to generate heat, to run construction vehicles, etc., on the construction site. Diesel, electricity, and fuel oil/furnace oil are the most common fuels consumed on-site for these activities. In the case of rural roads, use of kerosene and timber as fuels is also common.

It is expected that direct/on-site energy consumption and the resultant CO_2 emissions for the two construction technologies, that is, hot mix and cold mix technologies would vary on account of no requirement of on-site heating for the cold mix technology. In order to capture the difference in energy consumption for the two technologies, data collected from sample road stretches was analysed to derive energy consumption and CO_2 emissions per kilometre for construction and maintenance activities. Steps followed to estimate the energy and CO_2 impact due to on-site energy consumption include

1. Estimating the total energy consumed on-site (per km construction) for selected projects. Following data was collected for the selected projects to estimate this energy consumption:
   a. Electricity consumption (from grid)
   b. Energy consumption using generators
   c. Consumption of petroleum products and other fuels, such as timber
   d. Types and number of machinery and equipment used on-site
2. For energy consumption estimated in Step 1, embodied energy and CO_2 emissions were estimated by applying India-specific embodied energy coefficients and CO_2 emission factors. (Coefficients used in the model are discussed in Annexure 9.4.)

Similar to construction, road maintenance activities also require consumption of energy to operate equipment and machinery on-site. Maintenance data (of one year) for the two construction technologies was collected related to both routine maintenance and periodic maintenance (if available) to understand and compare the energy consumption for maintenance activities.

3.1.1.3 Indirect energy consumption and CO_2 emissions

Embodied energy and CO_2 in construction materials

Construction of any road requires consumption of materials. The production of most construction materials is an energy-intensive process, which also results in CO_2 emissions. This indirect energy consumption and CO_2 generation component related to material production, commonly referred as the 'embodied energy' and 'embodied carbon' of materials, was also estimated for both the construction technologies under study. This was done by

1. Estimating the quantity of materials consumed per kilometre of construction from the primary data collected for the selected road stretches;
2. Applying India-specific embodied energy and embodied CO_2 coefficients for materials to estimate total embodied energy and embodied $CO_2$of materials consumed per kilometre of construction. In case India-specific embodied energy and CO_2coefficients were not available, the same were derived from international literature [Coefficients used in the model are discussed in Annexure 9.4].

Transportation of construction materials

Once the materials are produced in the manufacturing units, these are transported to the construction sites by motorized modes, such as trucks. This requires consumption of energy (primarily diesel) by vehicles/ trucks transporting the construction materials and results in CO_2 emissions. This indirect energy consumption and CO_2 emissions was estimated by estimating the total fuel consumed due to transportation of materials required for per kilometre construction. Following data was collected for the selected projects to estimate this fuel consumption:

a. Quantities of materials transported and average leads for all materials
b. Mode of transportation (truck, dumper, tractor, transit mixer, rail, etc.) and its fuel efficiency
c. Average loading (per vehicle) and number of trips to transport materials

For each material transported, fuel consumption was estimated based on mode used, number of trips, and average lead (using average fuel efficiency values for the specific mode of transportation).

For the fuel consumption estimated in Step 1, embodied energy and CO_2 emissions were estimated by applying India-specific embodied energy coefficients and CO_2 emission factors. Table 9 summarizes the components considered for estimating indirect energy consumption and CO_2 emissions occurring on account of construction and maintenance of rural roads.

3.1.2 Generation of criteria pollutants

Road construction activities result in generation of pollutants such as carbon monoxide, nitrogen oxides, VOC, and particulate matter. One of the objectives of the study was to estimate the pollution generated on hot mix and cold mix construction sites on account of construction activities to enable a comparison between the two technologies in terms of generation of criteria pollutants. The methodology that was used to carry out this analysis is as follows

3.1.2.1 Methodology for ambient air quality measurement

As stated earlier, two Indian states, namely Uttarakhand and Assam, having different climatic characteristics were selected for the study. Hot mix

Table 9 Indirect energy consumption and CO_2 emissions: components considered

Components	Included	Remarks
Production of construction materials		
Embodied energy and CO_2 of construction materials	√	India-specific coefficients (Maini and Thautam, 2009)
	√	International coefficient values (Hammond and Jones, 2008)
Transportation of construction materials		
Direct CO_2 due to fuel consumption by vehicles transporting construction materials	√	India-specific CO_2 emission factors (MoEF, 2010; ARAI, 2007)
Embodied energy and CO_2 of fuel used	√	International coefficient values (TERI, 2010; Edwards et al., 2006)

Source: TERI *analysis*

and cold mix road construction sites were selected in both the states. For each site, two locations were selected for carrying out air quality monitoring - one in upstream direction and the other in the downstream direction to the constructions site.

Concentrations of VOCs and CO in air were measured simultaneously in the upstream and downstream direction of all construction sites for 8-hour period. Concentrations of PM_{10} and NO_x were measured for 24-hour period in both upstream and downstream directions of the construction sites at the same time during the winter season.

A control location was maintained at each site to measure the background concentration of different pollutants at the study site. The control locations were at least 1 km away from the construction site without any other (industrial, agriculture, transport, etc.) activities. At the control sites, the concentration of pollutants was measured at the same time as that of upstream and downstream measurement at road construction sites. At each of the selected locations, air quality monitoring equipment was installed as per IS 5182 (Part 14): 2000. Details related to sampling and analysis are provided in Annexure 9.2.

3.1.3 Health impact on construction workers

A questionnaire-based survey was conducted to assess the health impact of different road construction technologies on the construction workers and residents at the construction site. The questionnaires are provided separately for reference.

To prepare the questionnaire, RAND Corporation's 'Short Form Survey of 36 Items' (RAND-SF-36) approach was used. A set of different measures were included in the questionnaire following the approach outlined in the SF-36. Section 1,000 of World Health Organization's Health Survey, 2002,was referred to for selecting the measures to assess the socio-demographic characteristics of individuals. Personal interviews of workers/villagers were carried out at the construction sites.

The questionnaire was designed to assess the exposure duration, chronic diseases, and lung function of the construction workers and residents. All construction workers were interviewed in the survey. After completion of the survey in both the states, the data was analysed to draw a conclusion on the health effect of both hot mix and cold mix technologies on the health of the worker.

3.1.4 Resource use

3.1.4.1 Material consumption

Construction and maintenance of rural roads requires consumption of materials, both naturally occurring and processed materials. Many of the naturally occurring materials, such as natural aggregate, used for road construction and maintenance are limited/scarce and need to be conserved in order to reduce the resource footprint of construction and maintenance activities. Reducing or optimizing the usage of materials for road construction also has the benefit of reducing indirect energy consumption and emissions involved in manufacture/production and transportation of materials. Technologies that reduce material consumption for road construction and maintenance, hence, need to be promoted. The study focused on understanding and comparing the resource footprint/material consumption of the two construction technologies under study.

Material consumption data for construction and maintenance was collected for the sample rural road stretches selected for the study. Following materials were primarily found to be used:

Table 10 Road construction sites for which ambient air quality monitoring was carried out

State	Technology	Selected Road Construction Site for Air Quality Monitoring	Period When Monitoring was Carried Out
Uttarakhand	Hot mix	Bajoon to Adhora MR (Stage 2)	November 15–17, 2016
	Cold mix	Petsal–Bamanswal–Kapkot MR	November 17–19,2016
Assam	Hot mix	Majpathan to Bahuachu	December 22–26,2016
	Cold mix	L-039 Chemari to West Beloguri	December 22–24,2016

Source: TERI *analysis*

- Natural sand
- Coarse aggregate
- Cement
- Bitumen/bitumen emulsion
- Soil
- Brick
- Steel reinforcement
- Paint and primer
- Diesel/kerosene

3.1.4.2 Labour costs

The requirement of labour is expected to vary with change in technology used. The survey also included information on labour requirement for each component of road construction process in both the states. Further, labour was also classified as unskilled, semi-skilled, and skilled.

Since cold mix technology does not require on-site heating of bitumen, it is expected that use of unskilled labour would be less and use of skilled labour would be more relative to hot mix technology. This is expected to have significant impact on cost of projects using cold mix technology relative to projects using hot mix technology.

3.1.5 Road maintenance requirements

Road maintenance includes all those works, or activities, that are performed to maintain the pavement, shoulders, and other facilities provided for road users, as nearly as possible in their constructed conditions under given conditions of traffic loading and forces of nature. All components of the road pavement require maintenance as they are subjected to traffic and environmental effects. Maintenance requirements are dependent on design standards, traffic loading, terrain, soil type, local environmental phenomenon, etc. (TERI, 2012).

Routine road maintenance activities can be categorized into following two broad categories:

- **Routine maintenance** – Routine maintenance involves day to day repair of minor defects in existing facilities that need to be done quickly to arrest further deterioration and to ensure the safety of road users. These works are undertaken on an annual basis.
- **Periodic maintenance** – Periodic maintenance activities are undertaken at specified intervals on need basis to ensure structural integrity of the road to enable it to carry increased axle loads. Periodic maintenance is usually programmed as regular long-term maintenance works, and its periodicity depends on factors such as pavement design, traffic loads, environmental impacts, etc.

The routine maintenance history of the two rural road construction technologies under study, that is, hot mix and cold mix technologies, was done through selected sample road stretches in order to understand the differences in the maintenance requirements for the two technologies. The data on periodic maintenance was collected for the project where it was available and analysed as per the selected parameters. It should be noted that the data on periodic maintenance could be obtained only for the hot mix project studied under Phase 2 in Assam. For other projects, periodic maintenance data could not be obtained as most of the cold mix roads in the two states were relatively new and had not gone into periodic maintenance cycle. The results are discussed subsequently.

3.1.6 Project implementation

Project implementation would include time required for construction of project, weather conditions in which the two technologies can be used, and labour force requirement. Data on all these parameters was collected for the sample rural road stretches during the survey.

3.2 Life Cycle Analysis

3.2.1 NPV calculations

Given the social importance of rural roads, it is essential that a full LCA of costs be carried out at the design stage itself to economize on future expenditure as well as determine the correct technology choice depending on various construction parameters.

Apart from road construction costs, another component of expenditure on rural roads is routine maintenance, which is carried out every year. Also, periodically, the wearing course needs to be resurfaced to increase the longevity of the road (periodic maintenance). Periodic maintenance is an important determinant of life cycle costs as it is often more expensive than routine maintenance (IRC: SP: 20, refer Part 2). Further, if routine maintenance is regularly carried out, requirement of periodic maintenance can be postponed (International Labour Organisation, 2014). The difference in life cycle costs for hot mix and cold mix technologies would also, therefore, depend on frequency of periodic maintenance in stretches constructed using these technologies.

NPV calculations in this study are based on the following four components of road construction works:

- Cost of material
- Cost of transportation of material from source to project site
- Cost of equipment
- Cost of labour

These costs have been enumerated for following stages of rural road construction:

1. Earthwork
2. Drainage system
3. Grade, sub-grade, and base (pavement construction)
4. Wearing course (pavement surface)
5. Road markings and traffic signs

It was observed from the results of the study under Phase 1 that NPV calculations of life cycle costs could not be carried out for these projects as no project had undergone periodic maintenance even once in the five years since construction.

To overcome this constraint, a Phase 2 study was undertaken in which two new rural road stretches (hot mix and cold mix) of similar construction completion dates in Assam were chosen in which at least one stretch had undergone periodic maintenance at least once. The NPV of costs for these two stretches was calculated as follows.

3.2.1.1 Assumptions related to NPV calculations

1. In absence of Social Impact Assessment and Environment Impact Assessment documents, it is difficult to quantify, in monetary terms, the social and environment impact of hot mix and cold mix technologies for the selected projects under study. Therefore, monetary values of environment and social costs have not been taken into consideration in NPV calculations
2. It is assumed that all road stretches under study have been designed and constructed as per IRC and PMGSY guidelines for rural roads for defined performance
3. All calculations are subsequently done on a per kilometre basis for NPV calculations
4. A market cost of money at the standard rate of 10% has been assumed for discounting purpose. As per industry experts, this is the average interest rate at which banks lend for construction of rural roads projects on a conservative basis

It is important to note that these technology applications pertain mainly to the ‘wearing course’ (pavement surface). Hence, only costs related to wearing course are important to study life cycle costs and NPV related to these technologies. Therefore, NPV has been calculated only on the basis of wearing course costs.

4 Uttarakhand

4.1 Summary of Selected Projects

A summary of the projects under study in the state of Uttarakhand is given below.

Figure 5 Map showing location of sample rural road stretches in Uttarakhand

4.1.1 Projects under construction

4.1.1.1 Hot mix project

Bajoon to Adhora MR (Stage 2)	
District	Nainital
Total length	5.8 km
Life of pavement	10 years
No. of lanes	1
Right of way	5.5 meters
Carriageway width	3 meters
Shoulder width	1.25 meters
Drainage type	Causeway
Date when construction started	August 22, 2015
Expected date of completion at time of study	December 2016

Bajoon to Adhora MR (Stage 2) provides connectivity to village Adhora (population: 713) with an all-weather road. The project is situated in a hilly area; the average slope of the area is between 25° and 45°. Here, the winter and summer temperature varies between 5 °C and 25 °C. The average rainfall is approximately 1,200 mm, which mainly occurs in the month of June

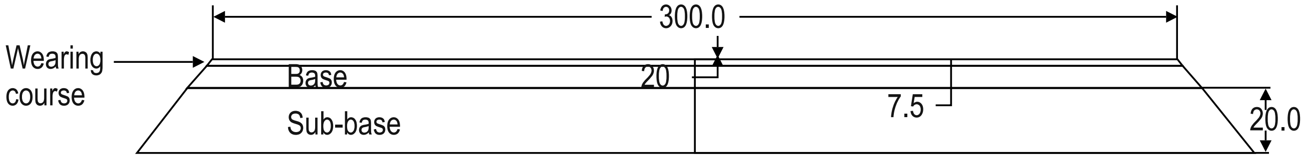


Figure 6 Cross-section diagram for sample rural road project using hot mix in Uttarakhand (Bajoon to Adhora MR [Stage 2])

Note: All values in centimetre
Source: As per data provided by site officials, URRDA

to September and December to January. Figure 6 shows the road layer design (thickness of layers) for the project which is under construction and using hot mix technology.

4.1.1.2 Cold mix project

Petsal–Bamanswal–Kapkot MR	
District	Almora and Bageshwar
Total length	15.175 km
Life of pavement	10 years
No. of lanes	1
Right of way	6 meters
Carriageway width	3 meters
Shoulder width	1.5 meters
Drainage type	Causeway
Date when construction started	June 18, 2013
Expected date of completion at time of study	December 2016

Petsal–Bamanswal–Kapkot MR provides connectivity to village Kapkot (population: 2,211) with an all-weather road. The project is at an altitude of 1,550 m from mean sea level. This road is situated in a hilly area with slope between 30° and 45°. The temperature of this area varies from 0 °C to 22 °C. The average rainfall is approximately 1,450 mm, which mainly occurs in July to August, December, and January. Figure 7 shows design thickness of layers for the project.

It is to be noted that, as reported by survey respondents, in both the projects, the soil mass reported good California Bearing Ratio (CBR) value, which facilitated utilization of existing strata as sub-grade. As a result, the sub-grade in both projects was prepared by fine dressing and rolling to achieve desired longitudinal and cross-sectional alignment.

4.1.2 Projects under maintenance

Projects under maintenance include those stretches from the sample that have been under routine maintenance for the past five years having been completed in 2012 or after. Data on these was collected for routine maintenance in any one year.

4.1.2.1 Hot mix project

Daniya–Ara–Salphar MR	
District	Almora
Total length	30.66 km
Life of pavement	10 years
No. of lanes	1
Right of way	6 meters
Carriageway width	3 meters
Shoulder width	1.5 meters
Drainage type	Side drain, scupper, culvert/ causeways
Date when construction was completed	August 2012

Daniya–Ara–Salphar MR provides road connectivity to eight villages. The project is located at an altitude of 1,300 m. It is situated in a hilly terrain with a slop varying between 25° and 60°.

4.1.2.2 Cold mix project

Pahariyadhar to Surang MR	
District	Nainital
Total length	11 km
Life of pavement	10 years
No. of lanes	1
Right of way	6 meters
Carriageway width	3 meters
Shoulder width	1.5 meters
Drainage type	Causeway
Date when construction was completed	Not available

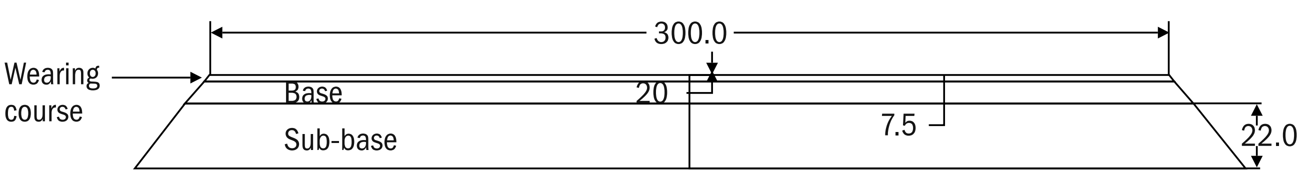


Figure 7 Cross-section diagram for sample rural road project using cold mix in Uttarakhand (Petshal–Bamanswal to Kapkot MR [Stage 2])

Note: All values in centimetre
Source: As per data provided by site officials, URRDA

Pahariyadhar to Surang MR provides road connectivity to village Surang with an all-weather road. The project is situated in hilly terrain, at an altitude of 1,350 m. The average slope of the area is between 30° and 50°. The temperature in this area varies between 0 °C and 24 °C. Rainfall mostly occurs in the months of July to September and December to February, and the average annual rainfall is approximately 1,400 mm.

4.2 Assessment Parameters

4.2.1 Energy consumption

Survey on sample rural roads in Uttarakhand found that rural road construction using hot mix technology consumes more energy than cold mix technology. This is true for both direct and indirect energy consumption as well as for projects under construction and under maintenance.

For under construction projects, total energy consumption was 1.7 times higher for hot mix projects compared to cold mix projects. Because hot mix technology requires heating bitumen on-site, direct (or on-site) energy consumption was nearly 10 times higher than cold mix technology project. This difference is due to use of biomass-based fuel (timber) for heating purpose. Indirect energy consumption due to materials was 1.2 times higher for hot mix than for cold mix. This difference is due to higher use of coarse aggregate in hot mix project relative to cold mix project (refer to Section 4.2.2.1). Another factor was high consumption of diesel for running on-site machinery, and the machinery was also used for a longer time in project using hot mix technology compared to project using cold mix technology. Indirect energy consumption for transportation of materials is 2.7 times more in hot mix project.

For wearing course construction, total energy consumption was higher for hot mix project than for cold mix project. It is important to note that while direct energy consumption is significantly higher (due

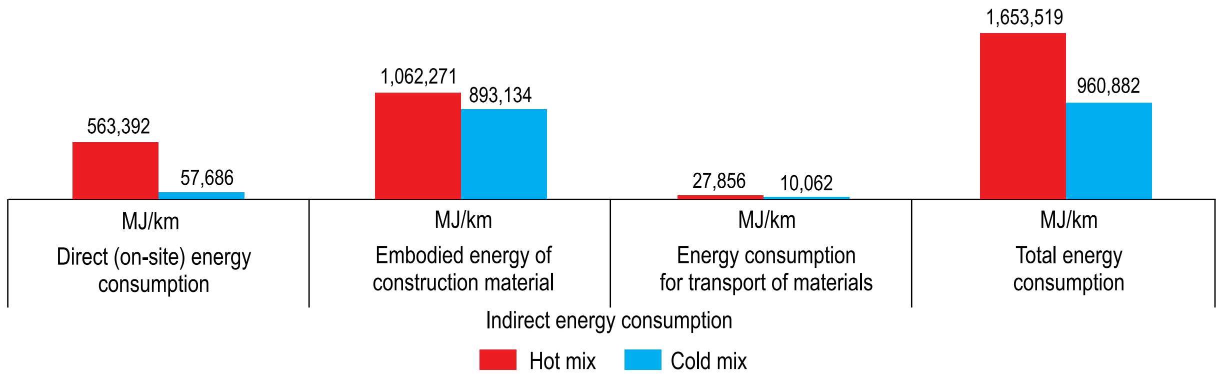


Figure 8 Energy consumption in under construction sample rural road projects in Uttarakhand

Source: TERI analysis

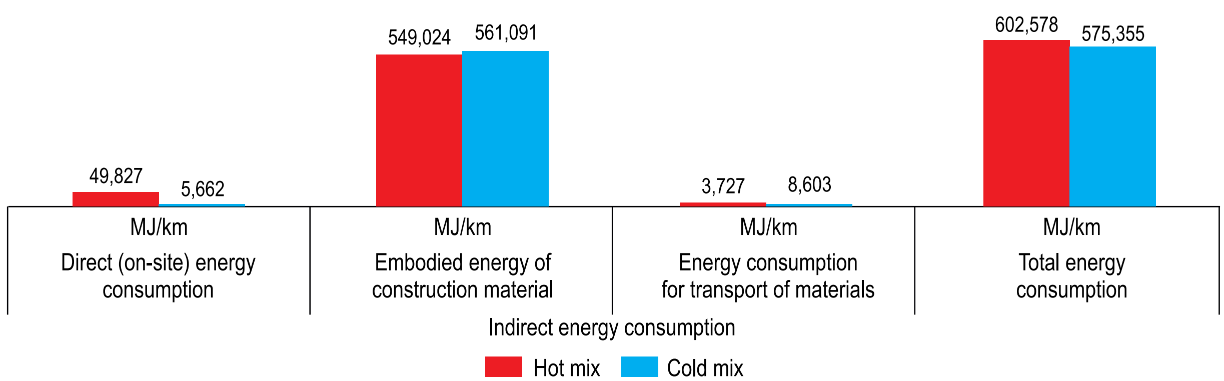


Figure 9 Energy consumption in wearing course construction in sample rural road projects in Uttarakhand

Source: TERI analysis

to use of timber and higher diesel consumption) for wearing course construction in projects using hot mix, indirect energy consumption on account of materials consumption and cost of material transportation (due to higher number of trips over longer distance) was higher for projects using cold mix.

For projects under annual routine maintenance in the State, total energy consumption was 2.8 times higher for routine maintenance for one year in hot mix project than in cold mix project. Direct (on-site) energy consumption was 11 times higher in hot mix than in cold mix project. Again, the use of biomass-based fuel (timber) for heating was the major cause of this difference. Indirect energy consumption was 2.3 times higher in hot mix than in cold mix.

4.2.2 Resource use

4.2.2.1 Material consumption

For under-construction sample rural road projects in Uttarakhand, material consumption on per kilometre basis inlaying of wearing course was slightly more in cold mix project than in hot mix project (Figure 11). This is because use of fine aggregate was higher in cold mix project.

In terms of total material consumption, project using hot mix consumed more coarse aggregate, fine aggregate, and cement compared to project using cold mix (Figure 12). Also, use of timber was higher in the project using hot mix technology. Although material was transported over long distances in project using cold mix, diesel consumption was higher in hot mix project than in cold mix project.

For annual routine maintenance purposes, total material consumption in hot mix project was 2.5 times higher compared to cold mix project (Figure 13).

4.2.2.2 Labour

In Uttarakhand, labour cost in project using cold mix

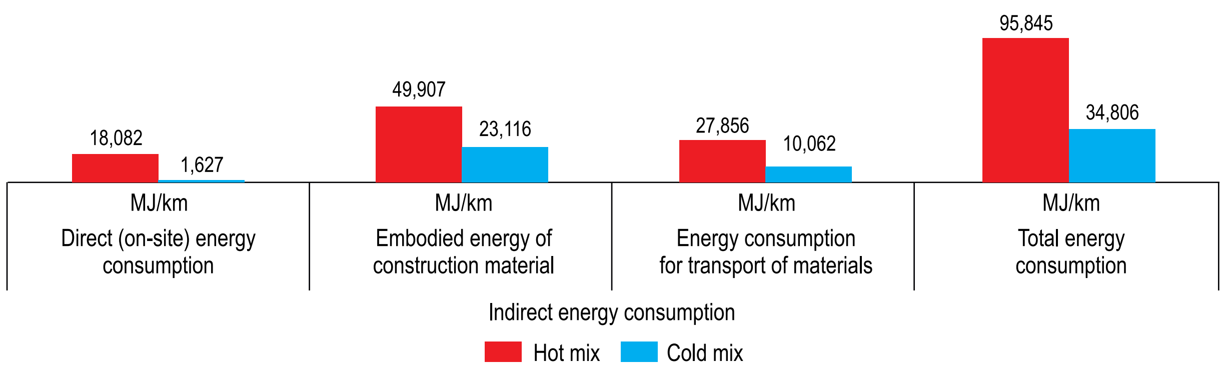


Figure 10: Energy consumption (annual) in sample rural road projects under routine maintenance in Uttarakhand

Source: TERI analysis

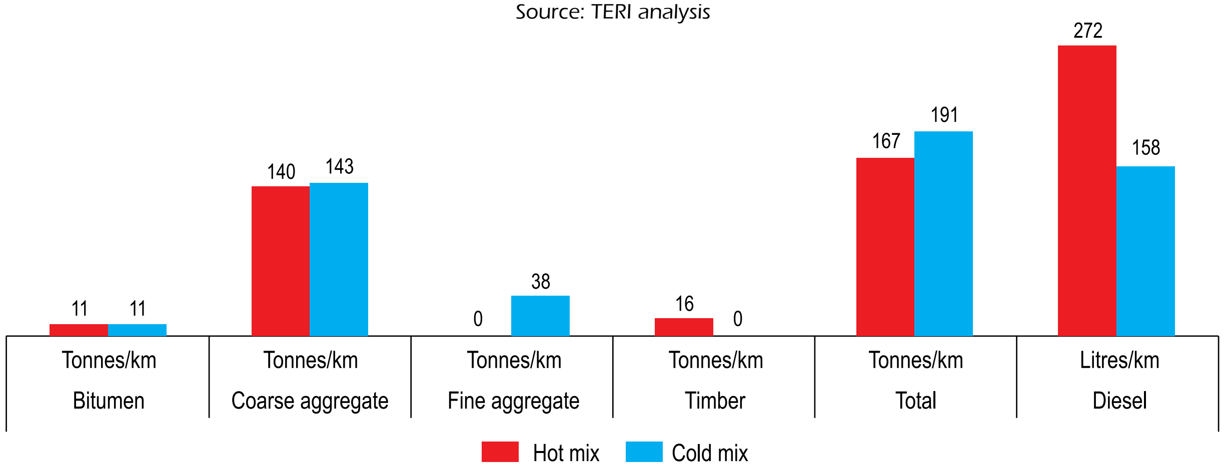


Figure 11 Material consumption in wearing course in under construction sample rural road projects in Uttarakhand

Source: TERI analysis

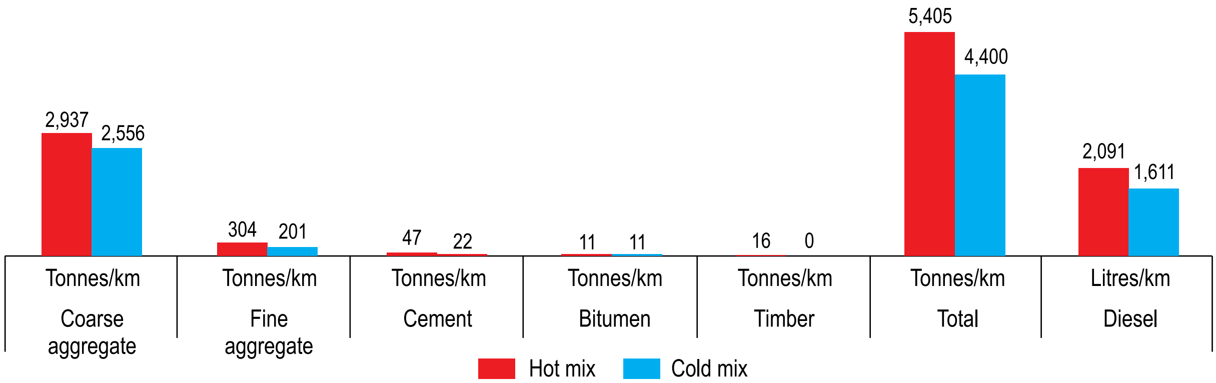


Figure 12 Total material consumption in under construction sample rural road projects in Uttarakhand

Source: TERI analysis

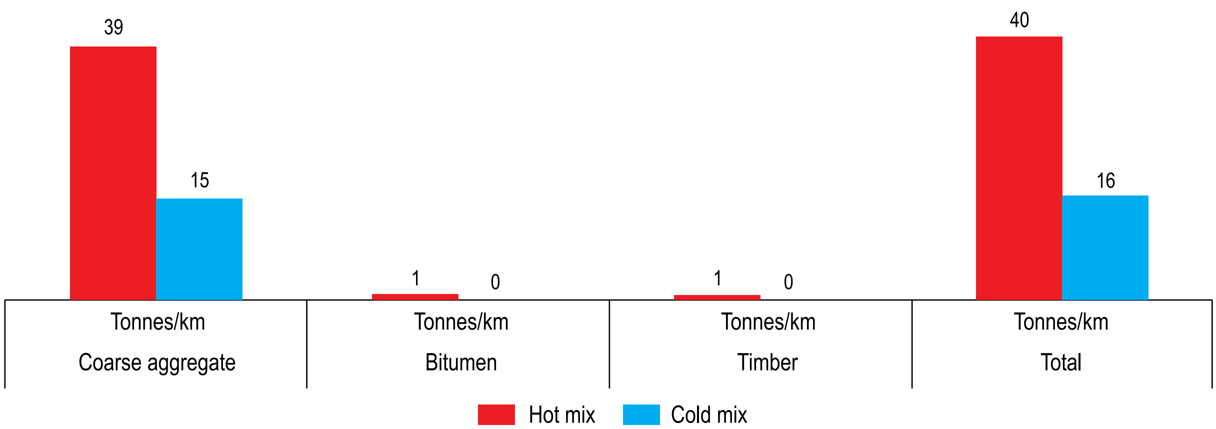


Figure 13 Material consumption (annual) in wearing course in sample rural road projects under routine maintenance in Uttarakhand

Source: TERI analysis

was higher at Rs 6.06 lakhs relative to project using hot mix which had a labour cost of Rs 4.97 lakhs. This was mainly on account of longer length of the project using cold mix (15.175 km as compared to 5.82 km in hot mix project). Labour used in each component of the sample rural road projects is given in Table 11. It can be observed that construction of wearing course utilized more labour in the cold mix project than in the hot mix project, indicating a slightly higher labour cost for cold mix project.

Table 11 Amount of labour used in sample rural road projects in Uttarakhand

Construction Component	Un-skilled	Semi-skilled	Skilled
Hot mix			
Earthwork and retaining walls	27	2	13
Drainage works	20	2	14
Base, sub-base, and sub-grade	11	1	1
Wearing course	11	4	0
Cold mix			
Earthwork and retaining walls	22	2	11
Drainage works	13	8	80
Base, sub-base, and sub-grade	25	1	1
Wearing course	21	7	0

Source: TERI analysis

4.2.3 Project implementation

4.2.3.1 Time required for construction works

It was observed that road constructed using hot mix technology took longer time as compared to road constructed using cold mix technology (Table 12). Construction of road using cold mix technology was faster as it did not require any on-site heating.

Table 12 Average construction duration for 1 km of rural road in Uttarakhand

State	Average construction duration (months) for 1 km of rural road	
	Hot mix	Cold mix
Uttarakhand	2.75	2

Source: As per data provided by site officials, URRDA, and TERI analysis

4.2.3.2 Weather conditions in which the two technologies can be used

Discussions with various stakeholders/consultants showed that cold mix technology is much easier and faster to work with. Since it does not require any on-site heating, it provides feasibility to work in all seasons, including cold and rainy season.

4.2.4 GHG emissions and criteria pollutants

4.2.4.1 CO_2 emissions

On an aggregate basis, due to high energy consumption and use of biomass (timber) in heating, CO_2 emissions due to direct (on-site) energy consumption were about seven times during under-construction phase in project using hot mix technology compared to project using cold mix technology. Also, due to higher quantity of coarse aggregate, fine aggregate, and cement used, CO_2 emissions due to embodied carbon were 1.6 times higher in hot mix project than in cold mix project. CO_2 emissions because of transport of materials were 2.7 times higher in hot mix project as more fuel was consumed to transport construction material over longer distance with frequent trips. Total CO_2 emissions were 2.2 times higher for hot mix technology than cold mix technology in projects under construction in Uttarakhand.

Consider only wearing course, CO_2 emissions were higher for project using hot mix technology than for project using cold mix technology. Direct (on-site) CO_2 emissions were higher for hot mix project due to use of fuels such as timber and diesel. However, transport of construction materials over longer distances and higher number of trips increased CO_2 emissions in cold mix project, which were higher by 2.3 times as compared to hot mix project. Indirect CO_2 emissions on account of materials were also higher for cold mix project, but the difference was not significant relative to hot mix project.

Also in projects under maintenance, total CO_2 emissions are higher for project using hot mix technology than for cold mix technology (annual routine maintenance). Use of timber in heating results in seven times more direct (on-site) CO_2 emissions in hot mix compared

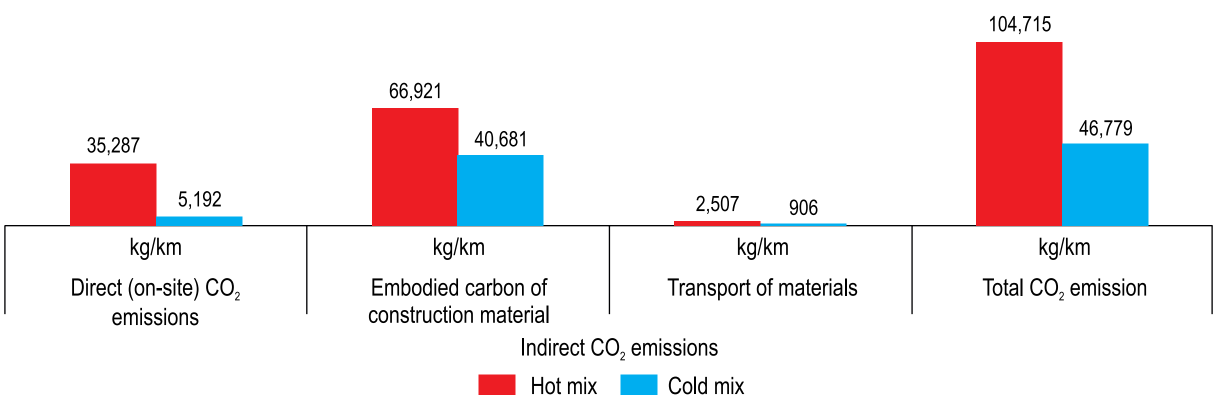


Figure 14 CO_2 emissions from under construction sample rural road projects in Uttarakhand

Source: TERI analysis

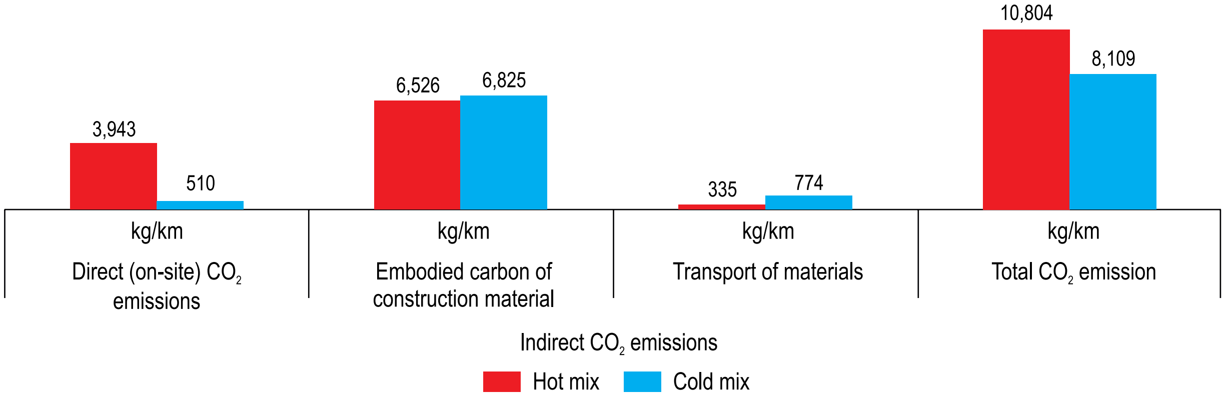


Figure 15 CO_2 emissions from wearing course construction in sample rural road projects in Uttarakhand

Source: TERI analysis

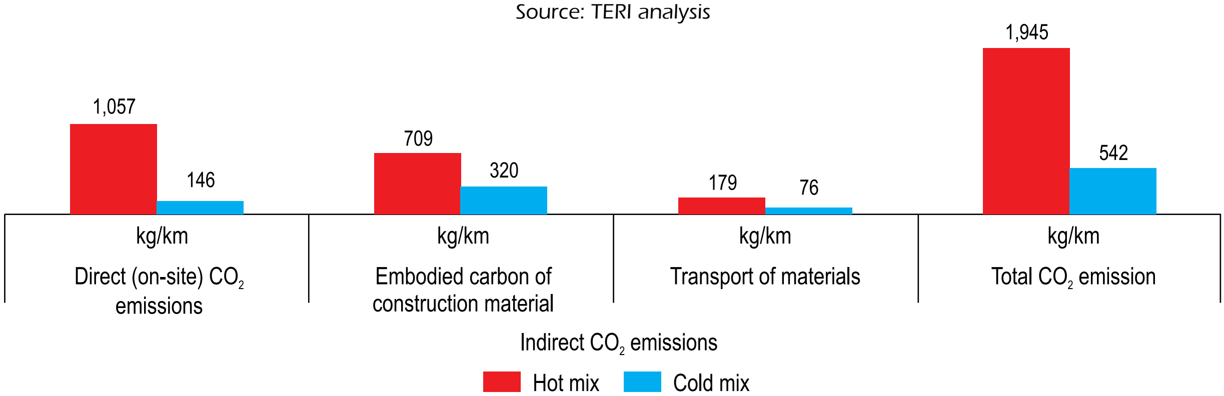


Figure 16 CO_2 emissions from under maintenance sample rural road projects in Uttarakhand

Source: TERI analysis

to cold mix. Indirect CO_2 emissions were 2.2 times higher in hot mix project. Total CO_2 emissions were 3.5 times higher in hot mix project as compared to cold mix project.

4.2.4.2 Generation of criteria pollutants

PM_{10}

The 24-hour average concentration of PM_{10} in both upstream and downstream directions at both

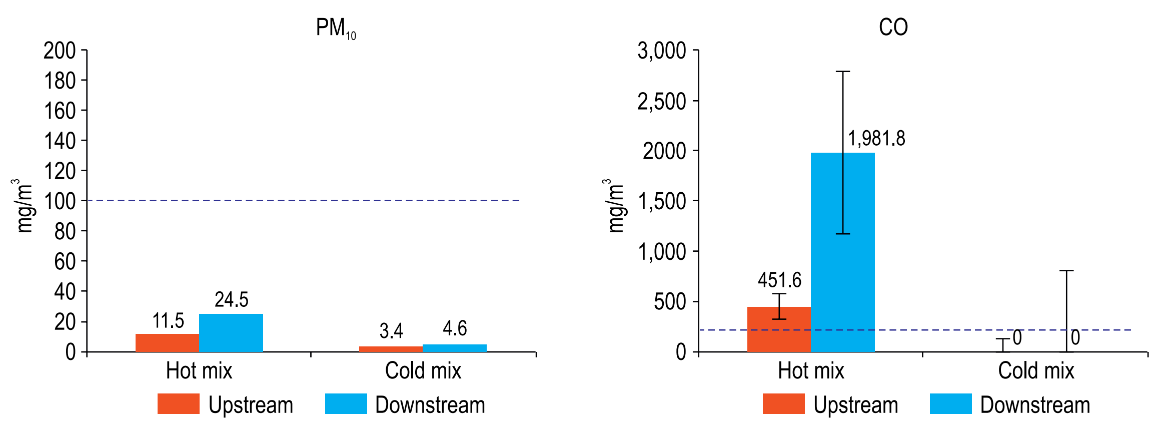


Figure 17 Concentrations of criteria pollutants at construction sites of selected rural road projects in Uttarakhand

Note: Bars indicate average of three replicated observations at each site. Error bars indicate standard error of mean. Dotted line denotes the National Ambient Air Quality (NAAQ) standard.

Source: TERI analysis

construction sites in Uttarakhand (both hot mix and cold mix) were well within the NAAQ Standard of 100 $\mu g/m^3$ (Figure 14). The upstream and downstream concentrations of PM_{10} at the cold mix site were 3.4 ± 1 $\mu g/m^3$ and 4.6 ± 0.5 $\mu g/m^3$; while at the hot mix site, the concentrations were 11.5 ± 8.5 $\mu g/m^3$ and 24.5 ± 9.5 $\mu g/m^3$, respectively.

The increase of PM_{10} concentration downstream of the construction site was higher when the hot mix technology was used compared to that in cold mix. The fuel used (mainly biomass based) during the use of hot mix technology for construction of rural road was mainly attributed towards increase in PM_{10} concentration downstream compared to that with the cold mix technology.

CO

The ambient concentration of CO was below the detectable limit of the instrument at the cold mix sites. The downwind concentrations of CO at the construction sites with hot mix technology were significantly higher than the 8-hour average NAAQ Standard of 228 $\mu g/m^3$ in Uttarakhand. The temperature at Uttarakhand sampling location (Nainital) was low. Hence, more fuel was required at the site to heat the bitumen for laying the road. Again, due to lower temperature, moisture content of the biomass fuel used at the Uttarakhand site was high. This might have contributed to the significantly higher concentration of CO downstream of the construction site with hot mix technology.

NO_x

The 24-hour concentration of NO_x was recorded well below (<6 $\mu g/m^3$) the NAAQ Standard of 80 $\mu g/m^3$ at all construction sites.

VOC

The VOC concentrations at all study sites were below the detectable limit of the instrument.

4.2.5 Health impact

The population density in Uttarakhand near the sample road project sites was low and settlements were sparse. Most of the road construction workers in the state are residents of Uttar Pradesh, Bihar, or Nepal. Labour for construction of roads is not available throughout the year. Average age of road construction workers in Uttarakhand is 37 years.

The questionnaire-based survey revealed that workers in the state of Uttarakhand were not aware about the safety measures. The literacy level of the workers was poor. Large numbers of workers (~42%) in Uttarakhand were illiterate. Due to poor level of literacy, the workers generally avoid regular medical check-up. As a result, they had no idea whether they were suffering from any chronic diseases (such as asthma, bronchitis, high blood pressure, etc.) or not.

The study could not draw any conclusion on the effect of different technologies on lung function of labour as they could not properly answer the number of years they have been working with cold mix and hot mix technology. However, it was noted that longer working period in the road construction job increases the probability of deterioration of the lung function, as indicated by increasing incidents of cough, breathlessness, phlegm during cough, etc.

4.3 Conclusion

On the basis of above results, it is evident that cold mix technology has inherent advantages in terms of savings in energy consumption, GHG emissions, and resource use. However, the results will depend on project-specific factors, such as materials used, use of labour, distance over which materials are transported, fuels used for heating of bitumen, etc. Once cold mix technology becomes more common in construction projects, it is expected that more conclusive results will emerge over time.

5 Assam

5.1 Summary of Selected Projects

A summary of the projects under study in the state of Assam is given below.

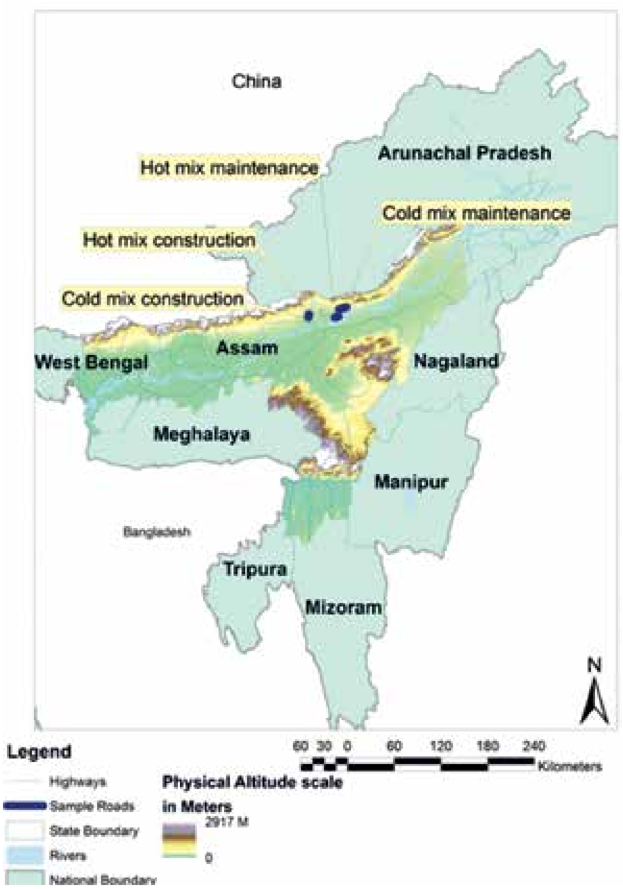


Figure 18 Map showing location of sample rural road projects in Assam

5.1.1 Projects under construction

5.1.1.1 Hot mix project

Ghoramari Buragaon to NH-52	
District	Sonitpur
Total length	1.2 km
Life of pavement	10 years
No. of lanes	1
Right of way	8 meters
Carriageway width	3.75 meters
Shoulder width	1.125
Drainage type	Slab culvert and box culvert
Date when construction started	February 28, 2014
Expected date of completion at time of study	January 2016

Ghoramari Buragaon to NH-52 stretch provides road connectivity to village Ghoramari Buragaon (population: 683) with all-weather road. The project is situated in a region with sub-tropical climate, which experiences dry hot summer and cold winters. Summer months are May to August. Heavy rainfall occurs annually leading to periodic floods. The annual average rainfall is 1,500 mm and humidity is 80%, with rainfall starting from early March. The annual temperature of the area ranges from 10 °C to 36 °C, where June–August are the hottest months while December and January are the coldest. The

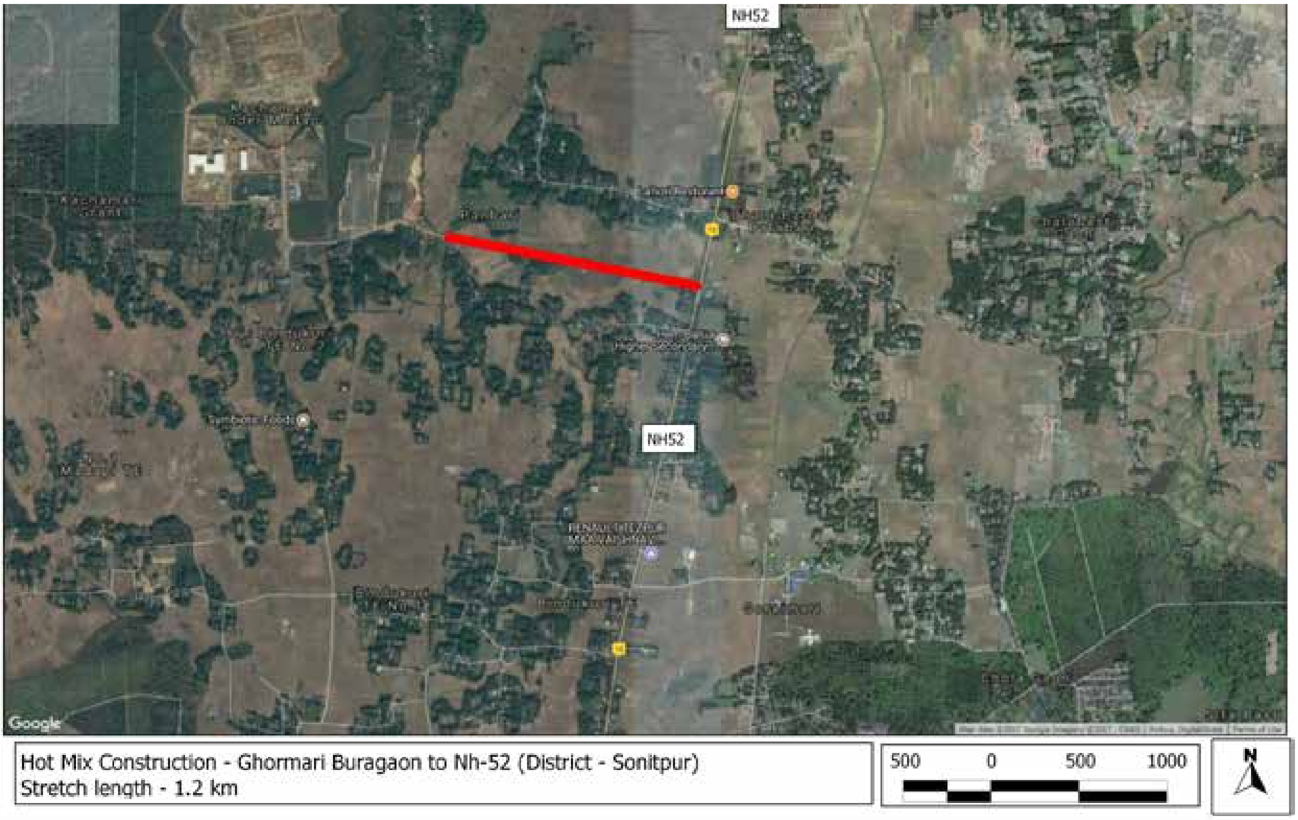


diagram showing road design layers (thickness of layers) for the project is given in Figure 19.

5.1.1.2 Cold mix project

Ghogra TE to NH-52	
District	Sonitpur
Total length	3 km
Life of pavement	10 years
No. of lanes	1
Right of way	8 meters
Carriageway width	3.75 meters
Shoulder width	1.125 meters
Drainage type	Slab culvert
Date when construction started	February 28, 2014
Expected date of completion at time of study	September 2016

Ghogra TE to NH-52 stretch provides connectivity to village Tezpur Ghagara (population: 706) with an all-weather road. The climatic condition of this road stretch is similar to the pervious site (Ghoramari Buragaon to NH-52) as they both fall in the same district of Sonitpur. The cross-sectional diagram for the selected sample rural road project under construction in Assam using cold mix is given in Figure 20.

5.1.2 Projects under maintenance

5.1.2.1 Hot mix project

Climatic conditions and other construction parameters were not available for this project as DPR was not provided.

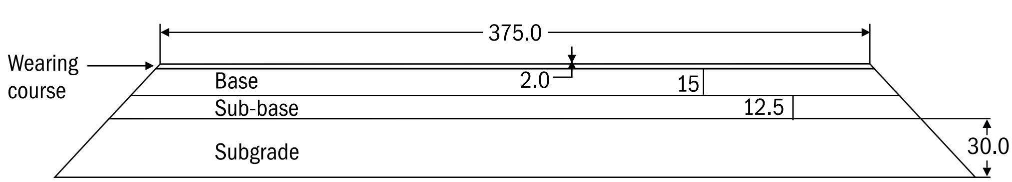
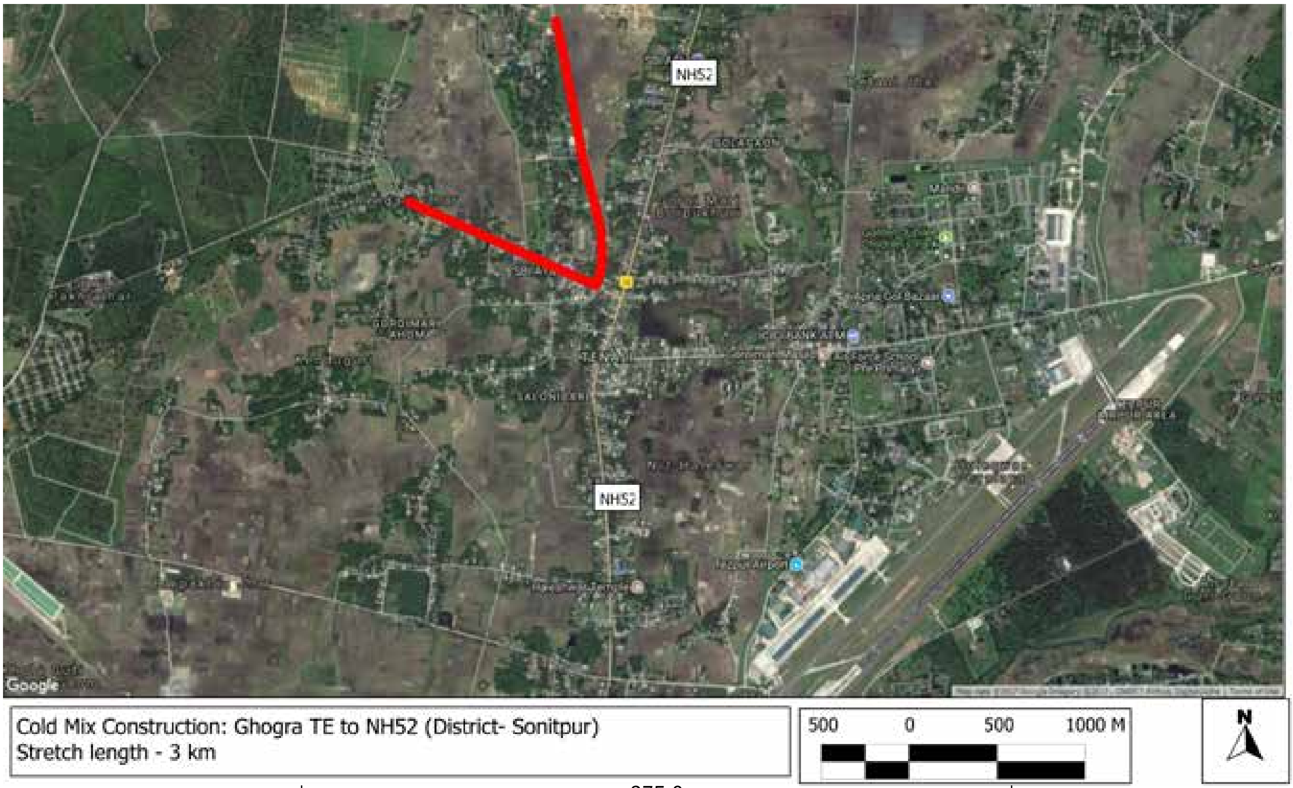


Figure 19 Cross-section diagram for sample rural road project using hot mix in Assam (Ghoramari Buragaon to NH-52)

Note: All values in centimetre
Source: As per data provided by site officials, Assam PWD



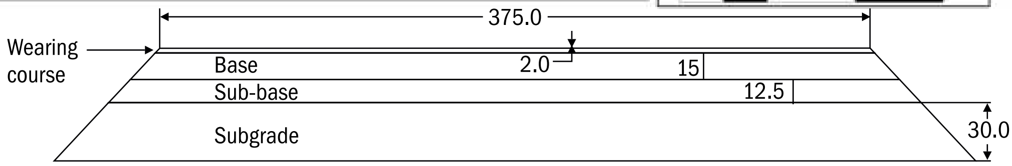


Figure 20 Cross-section diagram for sample rural road project using cold mix in Assam (Ghogra TE to NH-52)

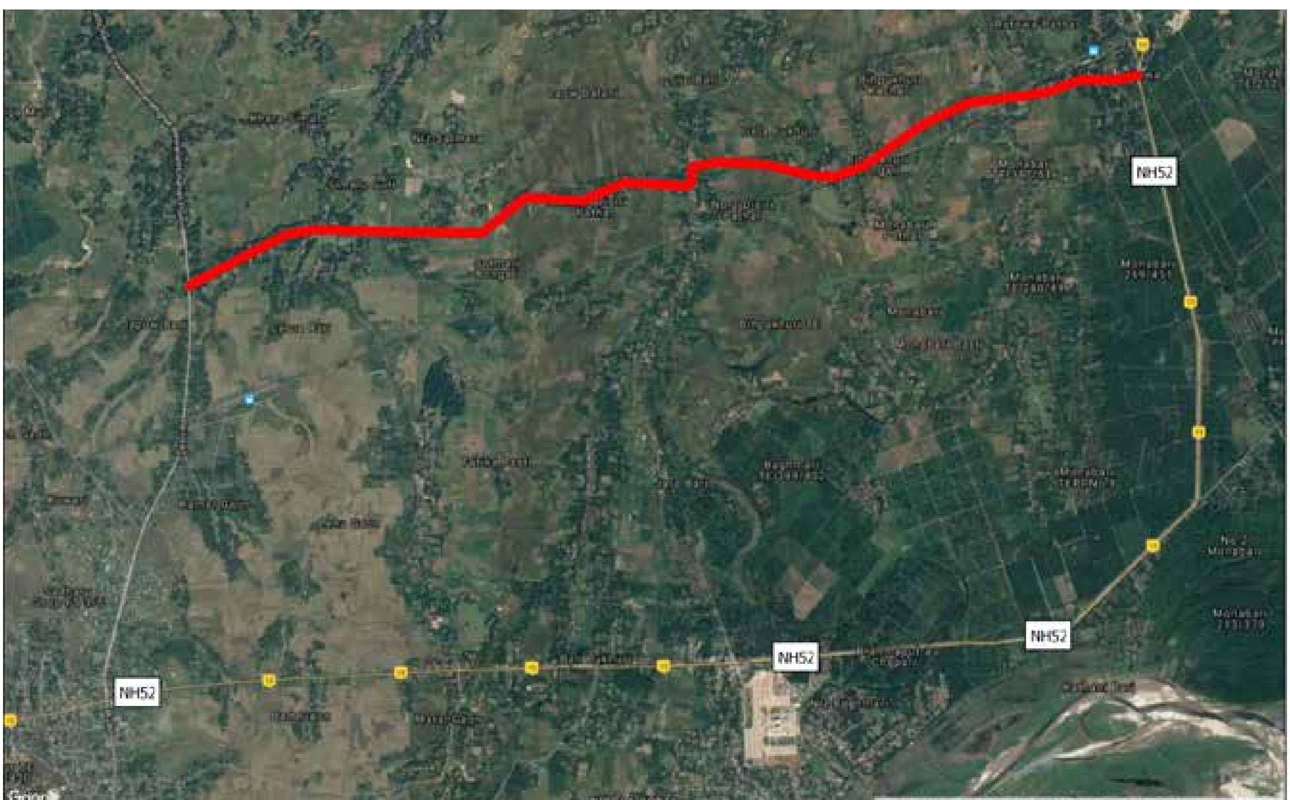
Note: All values in centimetre

Source: As per data provided by site officials, Assam PWD

Gorehagi to Chalia	
District	Nagaon and Sonitpur
Total length	6 km
Life of pavement	10 years
No. of lanes	1
Right of way	7.5 meters
Carriageway width	3.75 meters
Shoulder width	1.875 meters
Drainage type	Hume pipe
Date when construction was completed	October 2011

5.2.1.1 Cold mix project

Borpura to Rotuwa	
District	Tezpur and Dhemaji
Total length	8.92 km
Life of pavement	10 years
No. of lanes	1
Right of way	7.5 meters
Carriageway width	3.75 meters
Shoulder width	1.875 meters
Drainage type	Hume pipe
Date when construction was completed	October 2011



Cold Mix Maintenance - Borpura to Rotuwa (District - Tezpur and Dhemaji)
Stretch Length - 8.92 km

1000 0 1000 2000 3000 M

N

Climatic conditions and other construction parameters were not available for this project as detailed project report (DPR) was not provided.

5.2 Assessment Parameters

5.2.1 Energy consumption

The survey results in Assam show total energy consumption to be higher in hot mix as compared to cold mix for projects under construction (Figure 21). The difference in direct energy consumption (1.2 times in hot mix project) in project using hot mix vis-à-vis project using cold mix was due to use of kerosene for heating purposes. Use of large amount of cement for RCC works in earthwork and drainage for project using hot mix technology increased indirect energy consumption on account of materials as compared to project using cold mix. On the contrary, indirect energy consumption in transport of materials was more under cold mix relative to hot mix due to higher number of trips over similar distances to transport construction material.

In construction of wearing course, total energy consumption was higher in the case of cold mix project (1.2 times higher than hot mix project; Figure 22). Higher quantity of bitumen used increased the indirect energy consumption on account of material use in the cold mix project. Also, energy consumption for transportation of material in cold mix project was very high due to higher number of trips as compared to hot mix project. However, burning of kerosene for heating purpose was a major factor that drove up the direct (on-site) energy consumption in the hot mix project.

For sample projects under maintenance (annual routine maintenance) in Assam, energy consumption in hot mix project was higher than in cold mix project. Higher amount of construction materials (cement, coarse aggregate) used in the project using hot mix technology increased indirect energy consumption on account of materials. Overall, total energy consumption in project under maintenance in Assam using hot mix technology was twice of energy consumption in cold mix project (Figure 23).

5.2.2 Resource use

5.2.2.1 Material consumption

In Assam, material consumption in construction of wearing course in under-construction sample rural road projects was marginally higher in hot mix project as compared to cold mix project (Figure 24). Consumption of other construction materials remained nearly equal for hot mix and cold mix during wearing course construction. It is important

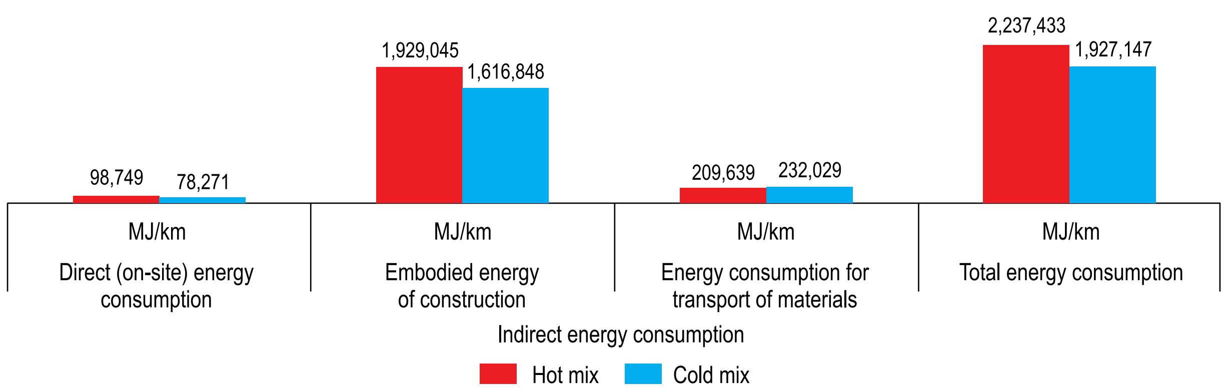


Figure 21 Energy consumption in under construction sample rural road projects in Assam

Source: TERI analysis

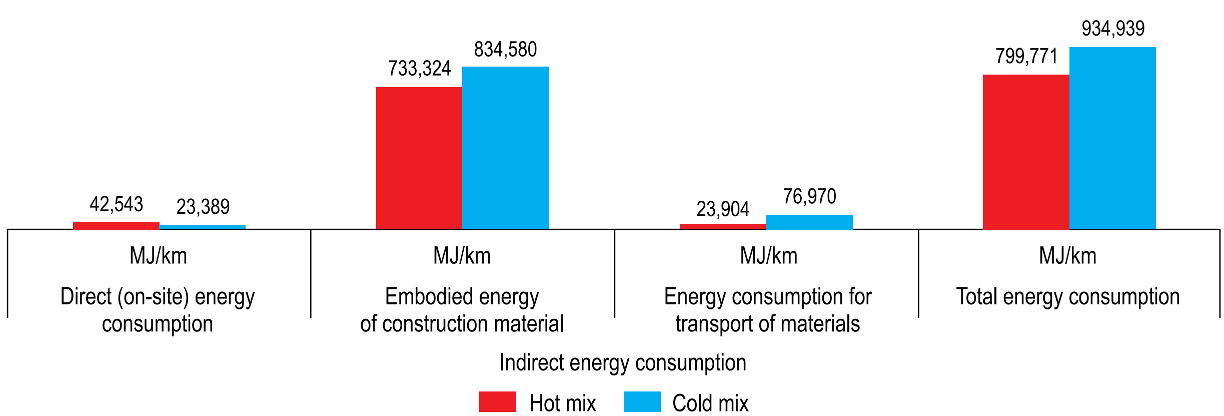


Figure 22 Energy consumption in wearing course construction in sample rural road projects in Assam

Source: TERI analysis

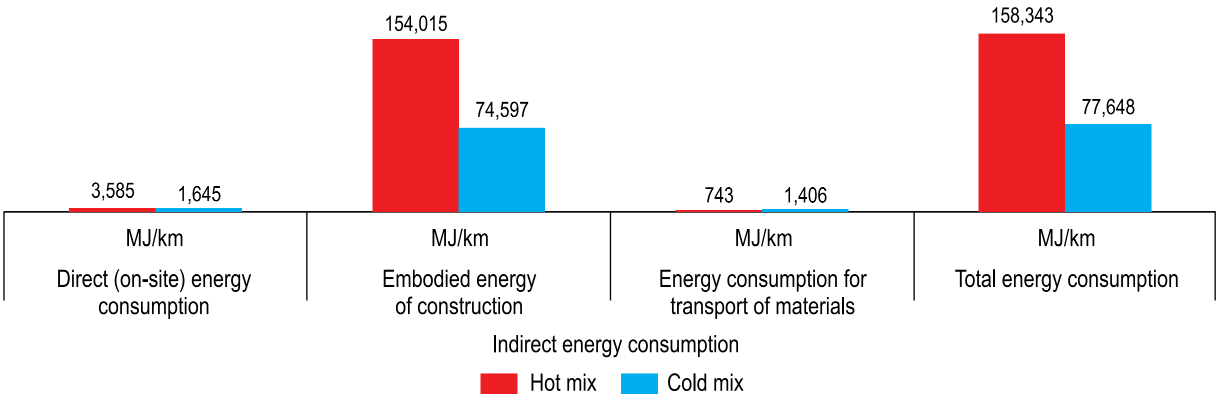


Figure 23 Energy consumption (annual) in sample rural road projects under routine maintenance in Assam

Source: TERI analysis

to note that there was high consumption of kerosene during heating of bitumen in hot mix project.

Total material consumption was higher in project using hot mix technology than project using cold mix technology (Figure 25). Hot mix project utilized higher amounts of coarse aggregate, RCC, and cement while cold mix project used higher amount of soil and bitumen.

For maintenance purposes, total material consumption in hot mix project was 1.6 times higher than in cold mix project in sample projects in Assam (Figure 26). Major difference was in use

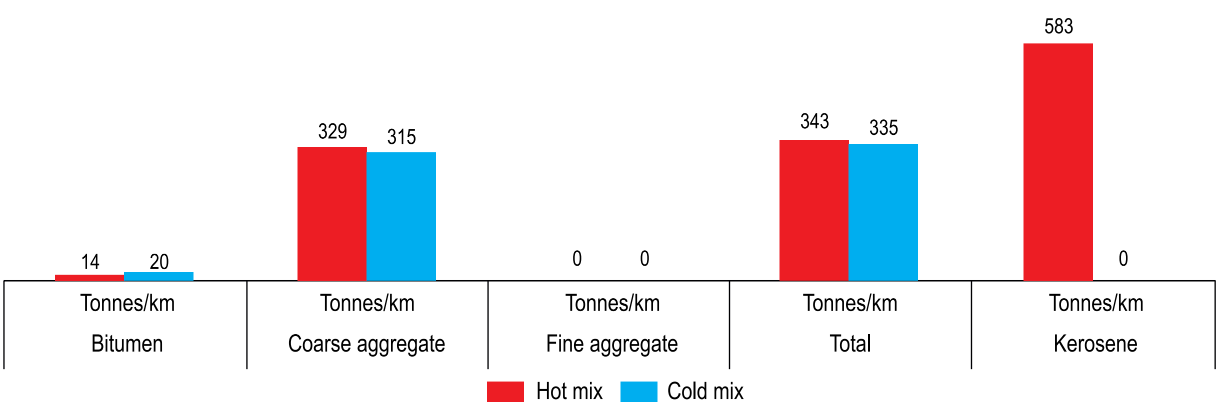


Figure 24 Material consumption in wearing course in under construction sample rural road projects in Assam

Source: TERI analysis

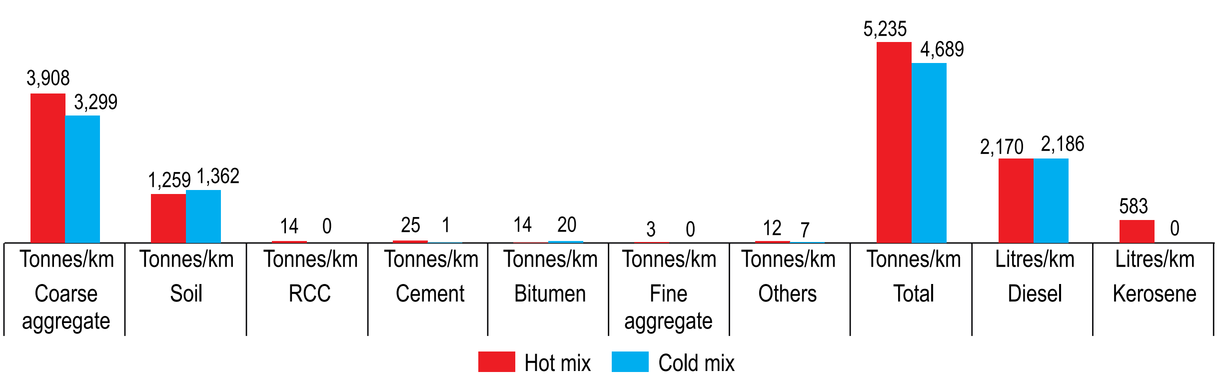


Figure 25 Total material consumption in under construction sample rural road projects in Assam

Source: TERI analysis

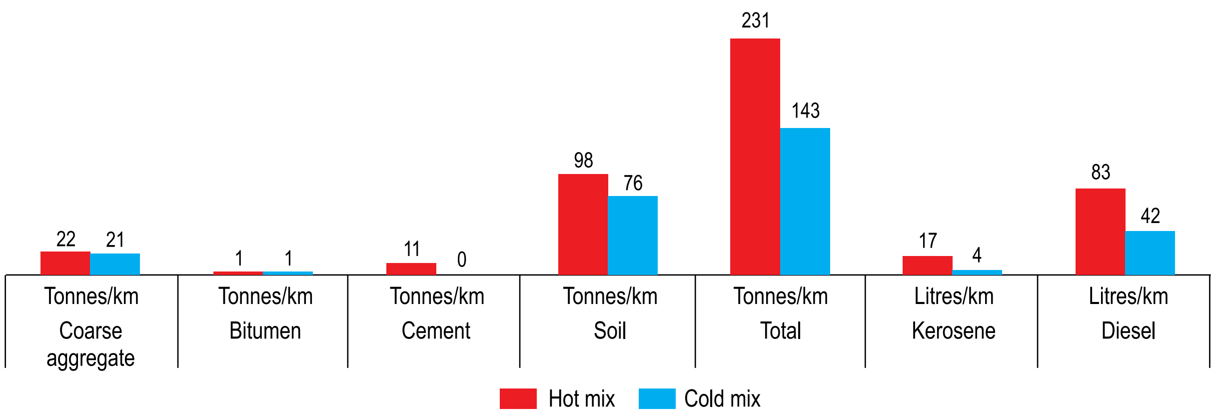


Figure 26 Material consumption in under maintenance sample rural road projects (annual routine maintenance) in Assam

Source: TERI analysis

of soil and cement due to local conditions of the project.

5.2.2.2 Labour

In Assam, use of un-skilled labour was higher in project using cold mix than in project using hot mix technology (Table 13). Semi-skilled and skilled labour was used more in project using hot mix than in project using cold mix. Total cost of labour was Rs 7.02 lakhs in project using hot mix technology and Rs 12.75 lakhs in project using cold mix technology. This difference was mainly on account of longer length of project using cold mix technology (3 km as compared to 1.2 km in hot mix project).

Table 13 Amount of labour used in sample rural road projects in Assam

Construction Component	Un-skilled	Semi-skilled	Skilled
Hot mix			
Earthwork and retaining walls	130	4	3
Drainage work	0	15	9
Base, sub-base, and sub-grade	25	10	6
Wearing course	15	3	2
Cold mix			
Earthwork and retaining walls	320	0	0
Drainage work	0	6	6
Base, sub-base, and sub-grade	25	10	6
Wearing course	15	5	3

Source: TERI analysis

5.2.3 Project implementation

5.2.3.1 Time required for construction works

In Phase 1, it was observed that road constructed using hot mix technology took longer time for construction on a per kilometre basis as compared to road constructed using cold mix technology (Table 14). However, in Phase 2, road constructed using cold mix technology took longer time on a per kilometre basis as compared to road constructed using hot mix technology.

Table 14 Average construction duration for 1 km of rural road in Assam

State	Average Construction Duration (months) for 1 km of rural road	
	Hot mix	Cold mix
Assam	19	10

Source: As per data provided by site officials, Assam PWD, and TERI analysis

5.2.3.2 Weather conditions in which the two technologies can be used

After having discussions with various stakeholders/ consultants, it was found that cold mix technology is much easier and faster to work with. Since it does not require any on-site heating, it is easy to work with cold mix technology in cold and rainy season.

5.2.4 GHG emissions and criteria pollutants

5.2.4.1 CO_2 emissions

As mentioned earlier, in the under-construction sample project using hot mix technology high amount of kerosene was used in Assam. This results in higher CO_2 emissions by use of hot mix technology relative to cold mix. But, CO_2 emissions was higher due to high energy consumption in transportation using cold mix technology compared to hot mix project. As a result of these two factors, the difference between projects using hot mix and cold mix was reduced to some extent in terms of total CO_2 emissions. Total CO_2 emissions were 1.4 times higher in hot mix project as compared to cold mix project (Figure 27).

During construction of wearing course, total CO_2 emissions were 1.3 times higher in cold mix project as compared to hot mix project (Figure 28). Long distance for transport of construction material with higher number of trips to transport bitumen in cold mix project was the major factor accounting for this difference. CO_2 emissions due to transport of materials were 3.2 times higher in cold mix project as compared to hot mix project. However, direct (on-site) CO_2 emissions were 1.7 times higher in hot mix project as compared to cold mix project.

For annual routine maintenance, total CO_2 emissions in project using hot mix were five times higher than emissions from cold mix project (Figure 29). This was mainly due to high amount of embodied energy in materials used in maintenance, namely cement and soil. Higher emissions take place in cold mix project due to transport of construction materials but the effect on total CO_2 emissions is insignificant.

5.2.4.2 Generation of criteria pollutants

PM_{10}

The 24-hour average concentration of PM_{10} was higher than the NAAQ Standard at both construction

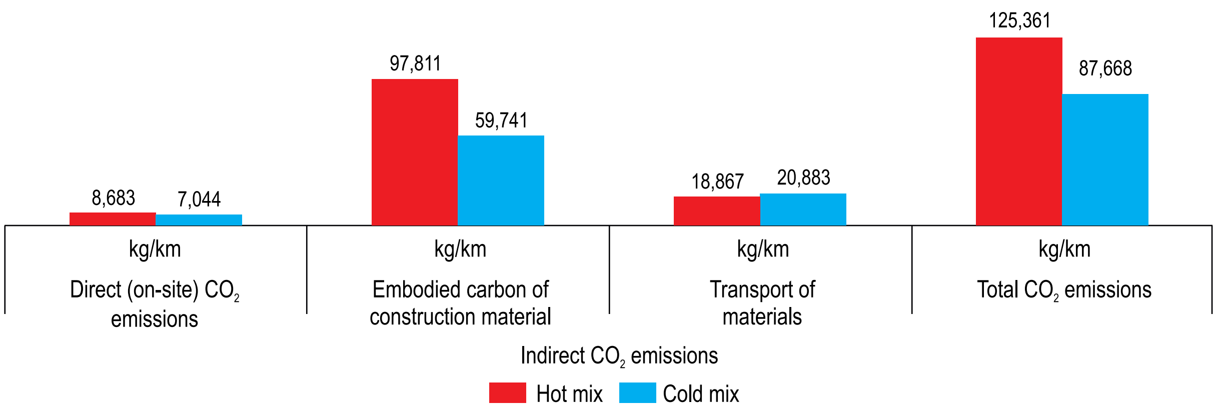


Figure 27 CO_2 emissions from under construction sample rural road projects in Assam

Source: TERI analysis

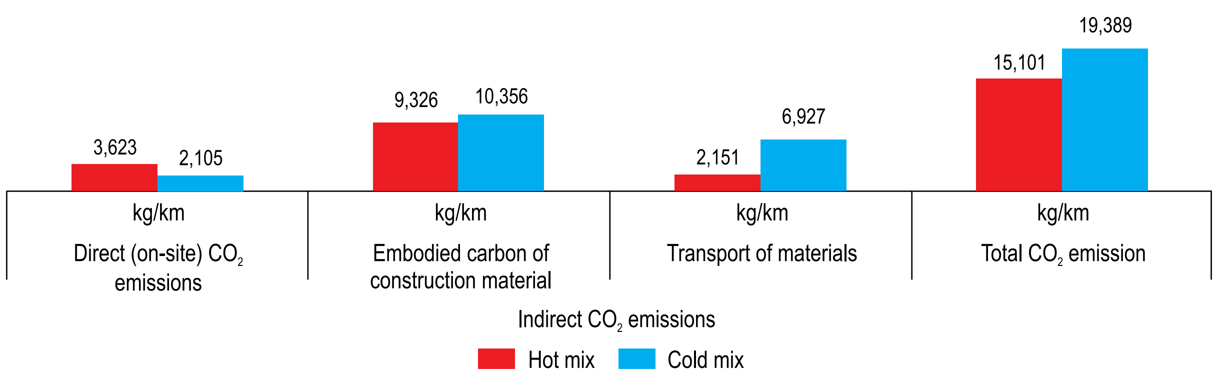


Figure 28 CO_2 emissions from wearing course construction in sample rural road projects in Assam

Source: TERI analysis

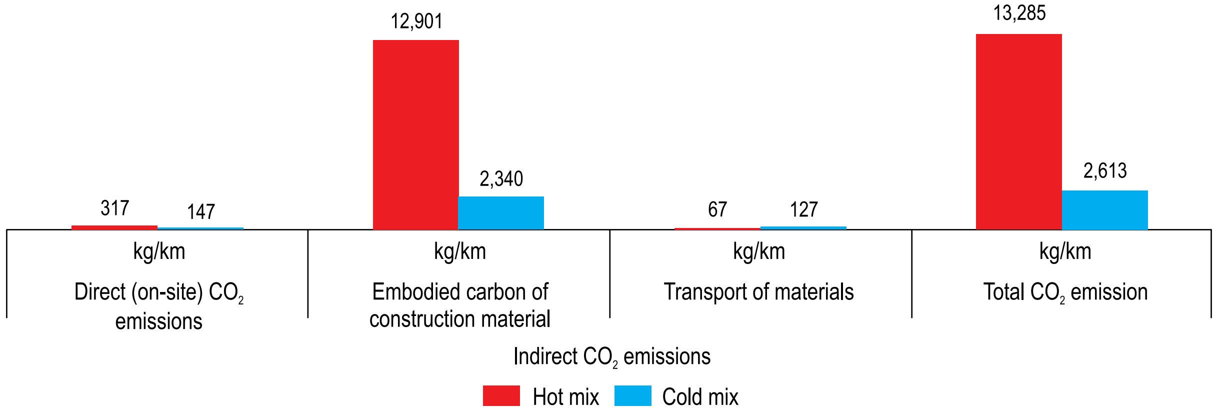


Figure 29 CO_2 emissions from under maintenance sample rural road projects in Assam

Source: TERI analysis

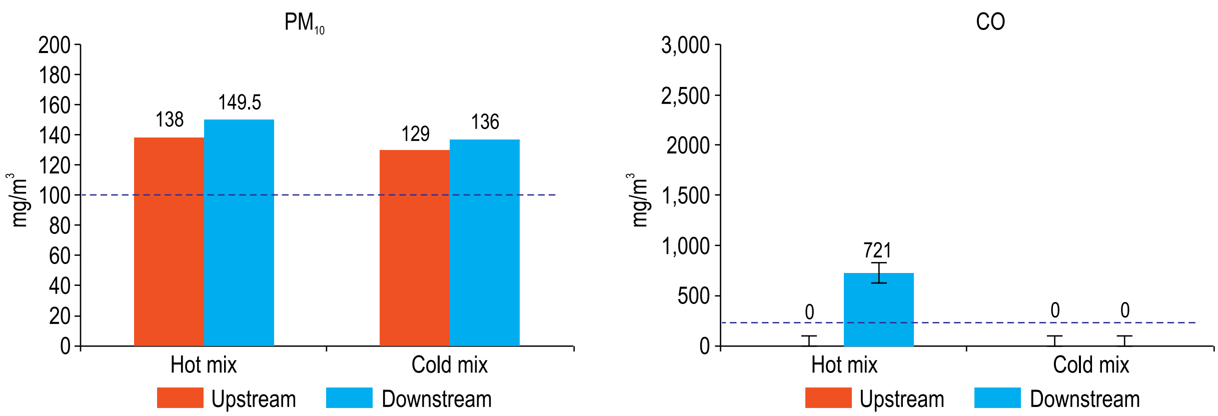


Figure 30 Concentrations of criteria pollutants at construction sites of selected rural road projects in Assam

Note: Bars indicate average of three replicated observations at each site. Error bars indicate standard error of mean. Dotted line denotes the NAAQ standard.

Source: TERI analysis

sites in Assam. The upstream and downstream concentrations of PM_{10} at cold mix site were 129.0 ± 12.6 $\mu g/m^3$ and 136.2 ± 11.5 $\mu g/m^3$ and at hot mix site were 138.6 ± 9.5 $\mu g/m^3$ and 149.5 ± 8.5 $\mu g/m^3$, respectively.

PM_{10} concentration downstream of the construction site was higher when hot mix technology was used compared to cold mix. The fuel used (mainly kerosene) during the use of hot mix technology for the construction of the rural road was main cause of higher PM_{10} concentration downstream compared to cold mix technology.

CO

The concentration of CO was below the detectable limit of the instrument at cold mix sites. The downstream concentrations of CO at the construction sites with hot mix technology were significantly higher than the 8-hour average NAAQ Standard of 228 $\mu g/m^3$.

NO_x

The 24-hour concentration of NO_x was recorded well below (<6 $\mu g/m^3$) the NAAQ Standard of 80 $\mu g/m^3$ at all construction sites.

VOC

The ambient VOC concentrations at all study sites were below the detectable limit of the instrument.

5.2.5 Health impact

The population density in Assam is low and settlements are sparse. Road construction sites in

Assam were near to a town and close to a Paper Mill. Average age of road construction workers in Assam was found to be 31 years.

The questionnaire-based survey revealed that most of the construction workers followed all safety measures in the state. Literacy level of the workers was poor. Due to poor level of literacy, the workers generally avoid regular medical check-up. As a result, they had no idea whether they were suffering from any chronic diseases (such as asthma, bronchitis, high blood pressure, etc.) or not. The study could not draw any conclusion on the effect of different technologies on the lung function of labour due to lack of proper answer pertaining to duration (in years) of working with cold mix and hot mix technologies. However, it was noted that longer working period in road construction job increases the probability of deterioration of lung function, as indicated by increasing incidents of cough, breathlessness, phlegm during cough, etc.

5.2.6 Net Present Value

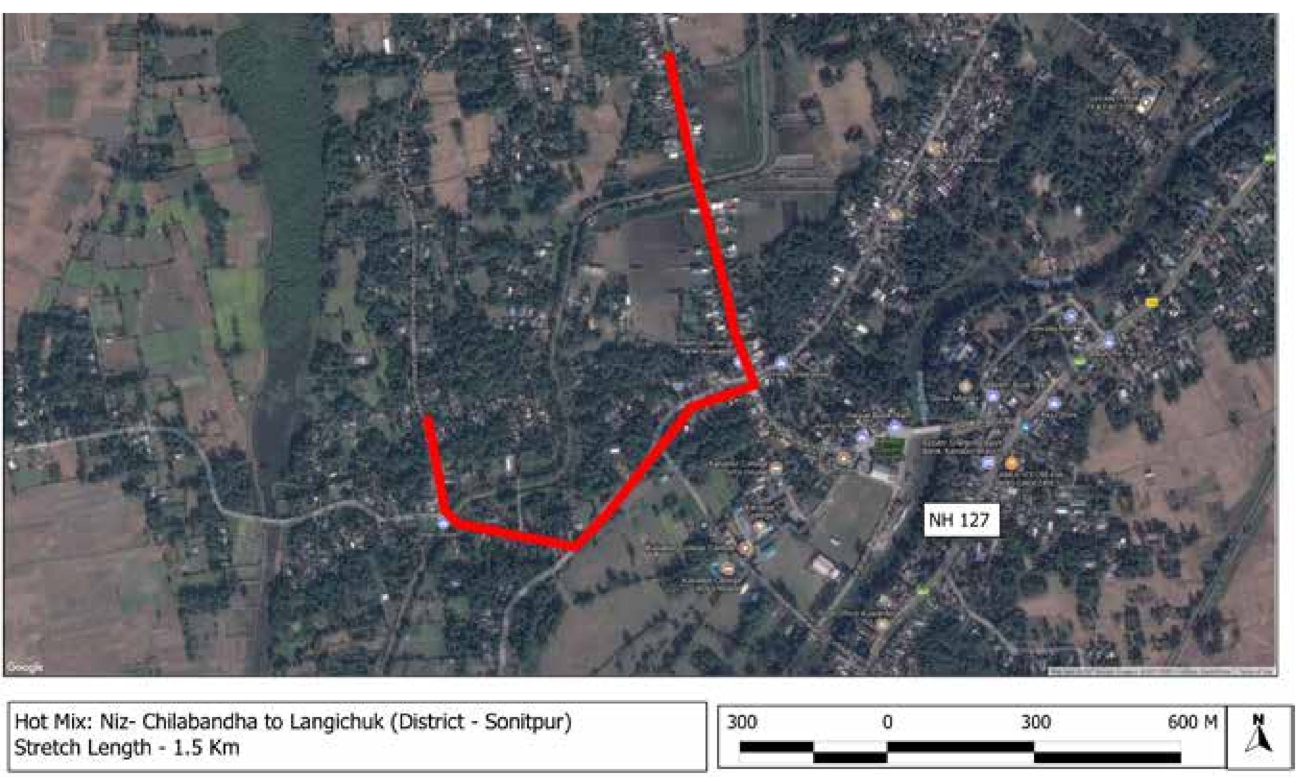
5.2.6.1 Criteria for project selection in Phase 2

The results obtained in Phase 1 were constrained due to one major issue. The rural road stretches (both hot mix and cold mix) had not undergone periodic maintenance even once in the five years since completion and had been undergoing routine maintenance only. As a result, correct NPV in terms of life cycle cost of projects could not be estimated without making strong assumptions.

To overcome this constraint, the criteria for project selection were revised based on the results of the study in the first phase and following were included

- Sample rural road stretches should be located very close to each other to minimize geographical/ terrain differences as well as differences in distance of transportation for construction materials;
- Project completion date for selected sample stretches should be in similar time period;
- Periodic maintenance should have been completed at least once in either rural road stretch in order to compare frequency of periodic maintenance required in hot mix and cold mix technology use.

The details of projects selected as per above criteria are as follows.



Hot mix project

Niz-Chilabandha to Langichuk	
District	Sonitpur
Total length	1.5 km
Life of pavement	10 years
No. of lanes	1
Right of way	12-15 meters
Carriageway width	3.75 meters
Shoulder width	1.875 meters
Drainage type	Hume pipe
Date of completion	November 30, 2009
Period under maintenance	7 years

Cold mix project

Dhekial to Sarubhogia	
District	Sonitpur
Total length	1 km
Life of pavement	10 years
No. of lanes	1
Right of way	12-15 meters
Carriageway width	3.75 meters
Shoulder width	1.125 meters
Drainage type	Hume pipe
Date of completion	August 10, 2009
Period under maintenance	7 years

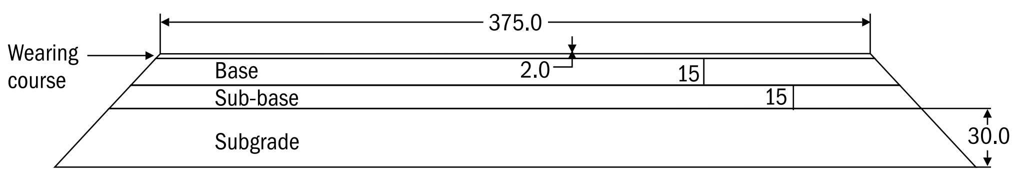
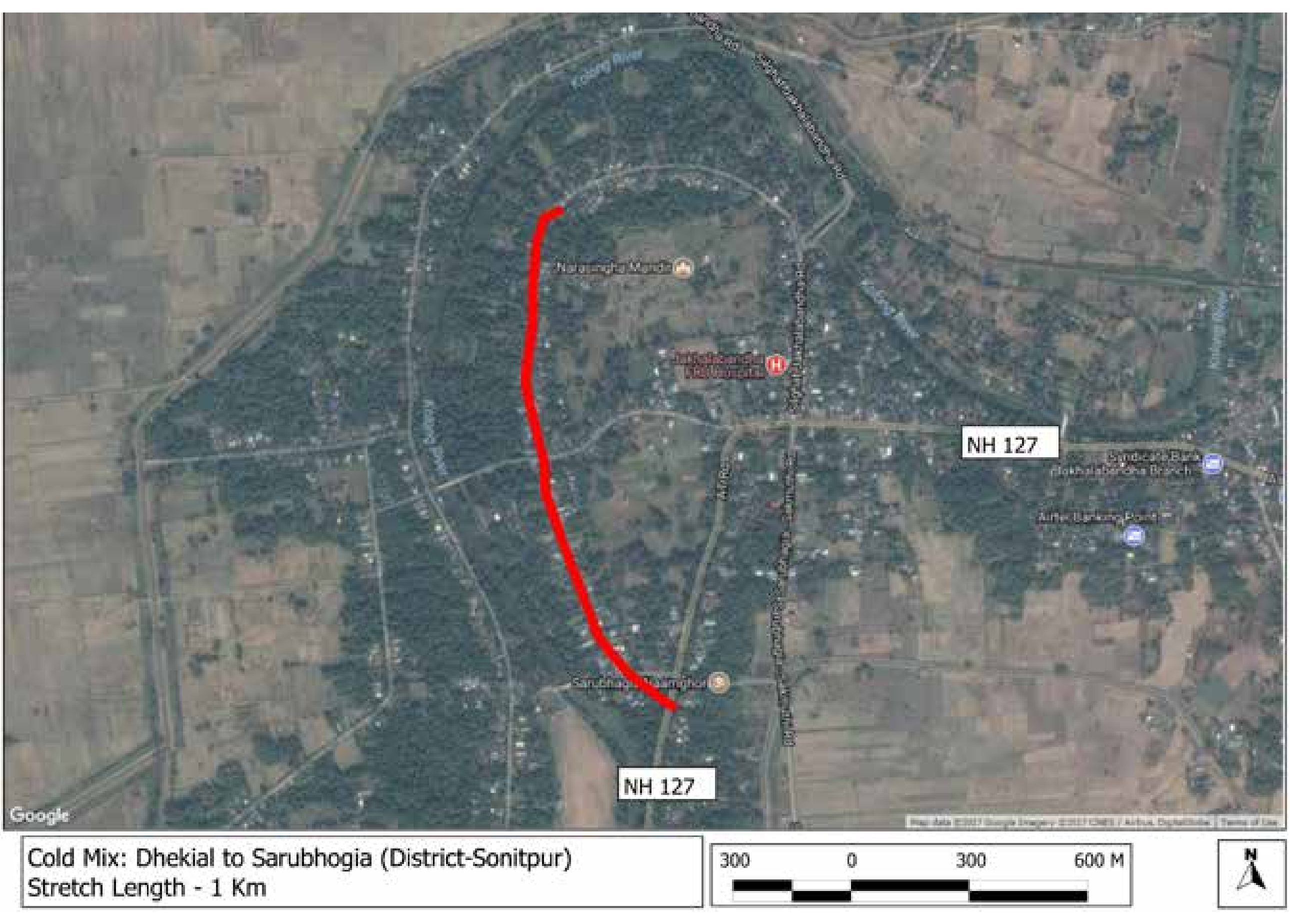


Figure 31 Cross-section diagram for sample rural road project using hot mix in Assam (Niz-Chilabandha to Langichuk) in Phase 2 of study

Note: All values in centimetre

Source: As per data provided by site officials, Assam PWD



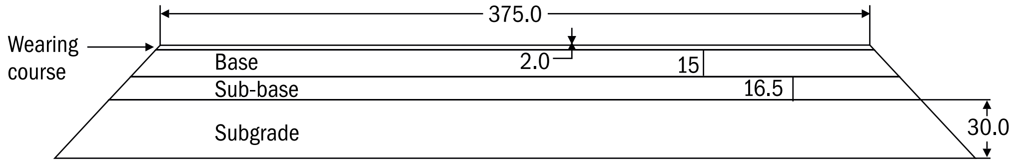


Figure 32 Cross-section diagram for sample rural road project using cold mix in Assam (Dhekial to Sarubhogia) in Phase 2 of study

Note: All values in centimetre
Source: As per data provided by site officials, Assam PWD

5.2.6.2 NPV calculation

NPV was calculated based on the following project information (Table 15) obtained during the study:

Table 15 Construction and maintenance costs of sample rural road projects

Project Parameters	Unit	Niz-Chilabandha to Langichuk	Dhekial to Sarubhogia
Length	km	1.5	1
Date of completion		February 28, 2009	August 10, 2009
Technology		Hot mix	Cold mix
Under maintenance for	years	7	7
Total cost	Rs	38,84,776	48,91,215
Total cost per km	Rs	25,89,851	48,91,215
Wearing course cost	Rs	7,90,900	8,52,900
Wearing course cost per km	Rs	5,27,267	8,52,900
Periodic maintenance cost	Rs	19,20,000	0
Periodic maintenance cost per km	Rs	12,80,000	0
Total routine maintenance cost till date	Rs	3,17,323	2,26,987
Total routine maintenance cost till date per km	Rs	2,11,548	2,26,987

Source: Project Implementation Unit of Assam PWD and TERI analysis

The routine maintenance cost incurred in each year in the sample projects is given below (Figure 33).

It is important to note that periodic maintenance cost on per kilometre basis (Table 15) was significantly higher than wearing course construction cost in the hot mix project. This was mainly because bitumen and coarse aggregate were procured at higher rates during periodic maintenance (2015/16) than during wearing course construction (2008/09).

From the results of NPV calculation given below (Table 16), it is evident that frequency of periodic maintenance would be important in determining present value of the costs in a project. Since periodic maintenance has been undertaken in project using hot mix once in 2016, total life cycle cost has increased

Table 16 NPV calculations for the sample rural road projects

Parameters	Year	Niz-Chilabandha to Langichuk Hot mix	Dhekial to Sarubhogia Cold mix
Wearing course construction cost per km (in Rs)		5,27,267	8,52,900
Routine maintenance cost per km (in Rs)	2010	0	13,380
	2011	12,449	15,756
	2012	14,666	52,384
	2013	48,825	66,032
	2014	61,553	79,435
	2015	74,056	0
Periodic maintenance cost in hot mix project (Rs per km)	2016	12,80,000	0
NPV		**13,18,786**	**10,11,866**

Note: Routine maintenance costs besides patchwork, pothole repair, include items such as clearing of drains, cleaning of berms, repainting of road signs, vegetation removal, etc. Such interventions are technology neutral.

Source: TERI analysis

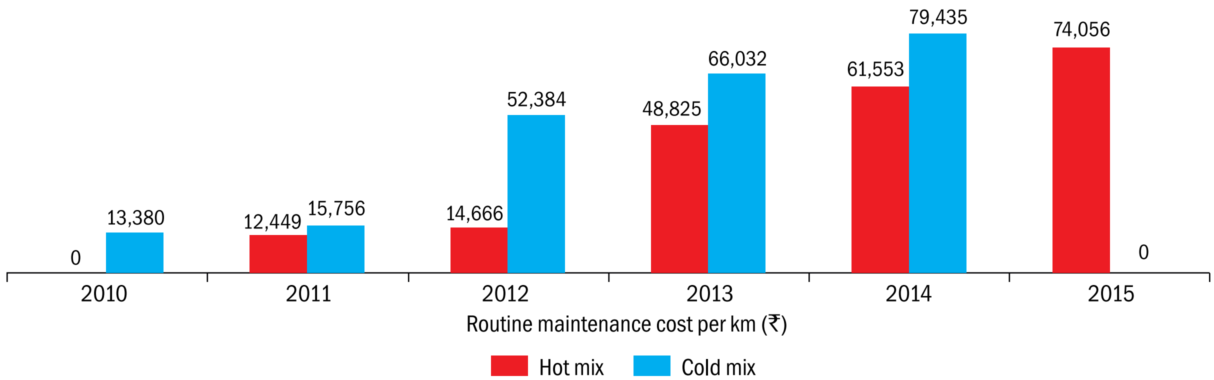


Figure 33 Year wise routine maintenance cost per kilometre in sample rural road projects

Note: In 2010, no routine maintenance was carried out for hot mix project as the construction of all the rural road stretches under the road package (AS-19-72) of which the sample stretch was a part, had not been completed. In 2015 and 2016, routine maintenance was not undertaken in the cold mix project as the pavement condition was robust and assessment revealed no requirement for routine maintenance activities.

Source: Project Implementation Unit of Assam PWD and TERI analysis

significantly. As a result, the NPV of costs in hot mix project was higher than in cold mix project as on date. Inflation in material and bitumen costs was another factor that drove up periodic maintenance cost for wearing course in comparison to construction cost.

5.2.7 Present site conditions

As per Project Implementation Unit, the condition of the stretch constructed using cold mix project was found to be satisfactorily robust after five years of routine maintenance so that there was no requirement for carrying out periodic maintenance so far. The wearing course could be reinforced from time to time through routine maintenance only.

In the past two years (2015 and 2016), no routine maintenance was carried out in the cold mix project due to satisfactory condition of the wearing course (Figure 34). Decision regarding type of maintenance to be carried out in the coming years would be taken on the basis of road condition and availability of funds for the roads package (AS-19-73) of which the stretch was a part.

In case of hot mix project, periodic maintenance had been undertaken in 2016 (9 months previously to date of site visit) due to which pavement condition was good although some signs of deterioration were beginning to appear. The present site conditions are depicted in the images below in Figure 35.

Present condition of cold mix stretch for first 100–300 m

Present condition of cold mix stretch in 300 m to 1 km

Figure 34 Present condition of sample rural road project using cold mix

Source: TERI

Figure 35 Present condition of sample rural road project using hot mix

Source: TERI

5.3 Conclusion

Special factors (such as use of kerosene in project using hot mix and higher use of bitumen in cold mix project) play a role in balancing energy consumption in both technologies to some extent. However, cold mix technology scores over hot mix technology in terms of lower generation of criteria pollutants. On an overall basis, cold mix technology results in both energy savings and less CO_2 emissions over the life of a rural road project.

Transport of materials over long distances (200 km, see Annexure 10.5) has significant impact on project costs. If transportation is made more economical, it is expected that cold mix technology will surpass hot mix technology in terms of savings on energy consumption, CO_2 emissions, and costs.

From NPV calculations of projects studied in Phase 2, it is evident that frequency of periodic maintenance would be a major determinant of difference in life cycle costs of hot mix and cold mix technologies in any project. Based on the study of these sample projects, it is clear that projects using cold mix technology do not require periodic maintenance for a longer time period as compared to hot mix project given similar site conditions. However, the result can be made more robust by studying similar projects that have been completed recently. As data from the first phase shows, this is because cold mix technology has nearly achieved parity in cost with hot mix projects, which is not the case for projects of second phase, which were completed eight years ago.

6 Recommendations

Presently, use of cold mix technology is mostly concentrated in the north-eastern states. Of the 4,900 km rural roads constructed using cold mix, 90% are located in the north-eastern region with heavy concentration in Assam (70%). The technology needs to be promoted and used in other states as well to comprehensively determine and demonstrate its advantages in terms of savings in maintenance costs, pollution, direct (on-site) energy requirements, carbon emissions, etc.

Based on the study and consultations with stakeholders, following recommendations are being made regarding use of cold mix technology for construction of rural roads:

6.1 Incentivize to lower cost of cold mix technology

Cold mix technology needs to be incentivized to make it more cost competitive. So far, construction using cold mix has been more expensive on per kilometre basis relative to hot mix, but the gap in costs has significantly narrowed down over the years due to changes in bitumen prices. However, bitumen prices being generally volatile, some additional support will be required to make cold mix more cost competitive keeping in mind the significant savings in maintenance costs relative to hot mix.

6.2 Economize on transport costs

As observed in the case of Uttarakhand, longer distance of transportation of materials has significant impact on energy consumption, embodied energy, and CO2 emissions. In Assam, remoteness of the project locations affects project costs for both hot mix and cold mix projects. It is necessary that cold mix plants are located at feasible distances to further economize transportation costs to bring it at par with hot mix technology. This can be done by setting up more production facilities in the country for cold mix.

6.3 Choice of cold mix technology should be based on objective criteria

State agencies and project implementation units (PIU) should select cold mix technology for projects by taking into consideration the following criteria

- **Need to extend working period** – Where there is a need to extend the working period for road construction, cold mix technology can be used. Short working periods are typically an issue in regions with high rainfall or cold weather, which restricts use of hot mix technology for a large part of the year. Cold mix technology could be a preferred technology in these regions. This is because cold mix has the advantage that it can be used in all weather conditions, such as in high rainfall areas, regions with very low temperatures, inaccessible regions, mainly due to absence of need for on-site heating
- **Availability of experienced contractors, labour and engineers** – Contractors either have prior experience or are willing to work with new technologies like cold mix. Trained workmen are available in the state or contractors/state agencies should be willing to train labour to apply cold mix technology in their projects. Engineers should also have the capacity to use cold mix technology with prior familiarity and experience in its use
- **Testing facilities for quality assurance of cold mix** – Facilities for testing quality of bitumen/

emulsion are accessible and reliable. It is essential for every contractor/engineer/PIU to get the design mix of materials tested by State Technical Agencies (STAs) to ensure that bitumen/emulsion meets requisite quality standards. STAs should have the capacity to appropriately assess the quality of the materials and analyse the impact of use of cold mix technology on road performance over its life

- **Capacity to carry out robust quality checks** – State Quality Managers (SQMs) and National Quality Manager (NQMs) are aware and understand the implications on road surface quality of the use of various technologies including cold mix and can carry out robust quality checks to boost confidence of stakeholders as well as local population in the advantages of use of cold mix
- **Incentives to engineers and officials for use of cold mix** – State agencies have developed incentive structures for engineers and officials to promote use of cold mix and other innovative technologies. For example, in Uttarakhand, additional points are awarded to engineers of Assistant Engineer level and above in their Annual Confidential Report assessment for use of new technology, cold mix, waste materials, etc.
- **Savings in energy consumption during transportation** – As per the results from the study, savings in on-site energy use from cold mix get offset if indirect energy consumption due to transportation of cold mix to project site is higher. Thus, the potential for savings in energy use due to transportation of cold mix, if it is available at feasible distances from the project site, should also be taken in to consideration.

PART -2
LITERATURE REVIEW

7 Literature Review

7.1 Rural Roads in India

7.1.1 Introduction

Since the medieval times, rural roads have played the role of connecting habitants from the villages to the nearby cities and towns. As the economy of the country grew, these rural roads have grown to become the basic infrastructure needed for the survival of rural citizens providing them with opportunities for socio-economic development, helping them access basic necessities, such as education and health services and employment. In India, there are about 6 lakh rural habitations of which about 40% are not connected with all-weather roads (NRRDA, 2015).

Rural roads network has grown at a remarkable pace since independence. With a CAGR of 4.57%, the rural roads network increased from 204,061 km in 1951 to 3,159,639 km by the end of 2013 (MoRTH, 2015). Providing connectivity to the majority of the population, the rural roads network accounts for 60.4% of the total road network length in the country. The rural roads in India comprise Village Roads (VRs) and Other District Roads (ODRs), serving to connect rural habitations with the state highways and national highways.

Rural roads are the most important part of the physical infrastructure in the country as they are a crucial requirement for eliminating poverty in the rural areas. Although rural roads are a state subject, the Government of India has put in lot of effort to improve the condition of rural roads through several rural development programmes. The government established the National Rural Roads Development Agency, State Rural Roads Development Agencies, and launched the Pradhan Mantri Gram Sadak Yojana (PMGSY) to accelerate the construction of rural roads in the country.

7.1.2 Pradhan Mantri Gram Sadak Yojana

One of the major rural development programmes initiated by the Government of India, PMGSY was launched on December 25, 2000. With an aim to ensure 100% connectivity to all the rural areas in India by the 9th Five-Year Plan, the PMGSY had a target to build 378,000 km of all-weather roads along with the upgradation of 375,000 km of rural roads and connecting more than 178,000 villages across the country. The priority of the PMGSY is to provide connectivity to rural habitations with a population of more than 500 people, in plain areas, and more than 250 people, in mountainous and desert locations (MoRTH, 2015).

The programme is implemented by the National Rural Roads Development Agency (NRRDA). Funded by the central government through the Central Fund for Roads (CFR), the PMGSY has also gained recognition and funding from the World Bank, Asian Development Bank, and other multilateral agencies under the Country Assistance Strategies. Table 17 provides a summary of the selected achievements of the scheme.

7.2 Construction of Rural Roads in India

The road structure is divided into four major components, namely, land, earthwork, pavement, and cross-drainage works. The pavement constitutes nearly one-third to one-half of the total cost of the road. Therefore, careful consideration should be given for the choice of the type of pavement and its design (Indian Roads Congress, 2002).

The various kinds of road pavements are:

Table 17 Summary of selected works carried out under the PMGSY

Parameters	
Total road length (in km)	1,443,937.70
Black topped road length (in km)	1,100,143.92
Water Bound Macadam road length (in km)	75,233.81
Gravel surfaced roads (in km)	91,632.66
Track surfaced roads (in km)	137,330.46
Other surfaced roads (in km)	39,596.87
Habitations connected	
Total	918,556
1000+ population	151,547
500–999 population	122,510
250–499 population	99,661
<250 population (Not eligible under PMGSY)	105,853
Habitations unconnected	
Total	479,571
1000+ population	60,433
500–999 population	99,287
250–499 population	120,843
<250 population (Not eligible under PMGSY)	158,422

Source: http://omms.nic.in/; last accessed on August 14, 2017

1. Flexible pavement
2. Cement concrete pavement
3. Composite pavement with semi-rigid base with suitable bituminous surfacing
4. Semi-rigid base with surfacing of interconnected concrete paving blocks
5. Roller compacted concrete.

The factors which are considered for the selection of the type of pavement are:

1. Initial (construction) cost
2. Availability of good construction materials locally
3. Cost of maintenance or rehabilitation during service
4. Technology required for construction and its availability

According to IRC: SP: 20-2002, flexible pavements are usually an appropriate choice for rural roads due to several advantages that they have over other pavements. As stated in IRC: SP: 20: 'In case of rural roads, in view of the stage, development strategy, and the initial cost advantage, the flexible pavement may be the appropriate choice. However, in special cases, in short sections or in some rural road projects where the ground conditions and material availability may pose restrictions for the use of flexible pavement, the other options, such as roller compacted concrete, block pavements, and composite pavements may be cost effective' (Indian Roads Congress, 2002).

There are various technologies used for construction of roads but the 11th Five Year Plan committee report suggests that there are three methods of road construction prevalent in India. They are:

1. **Conventional**: it is labour-intensive.
2. **Mechanized**: it is intensive in the use of machines.
3. **Intermediate**: it is mostly labour-intensive and uses machines only for operations, such as loosening the soil for excavation, site clearance, loading and unloading activities, spreading of soil, etc.

For constructing rural roads in India, the intermediate method is used. In the conventional method, the desired speed of construction is not achieved and the mechanized method is capital intensive. The intermediate method on the other hand provides employment to the local people and is not very costly.

The following section discusses the designing of pavements and materials used in the construction of rural roads in India as prescribed under IRC: SP: 20-2004 codes. The section further discusses the technologies used in the building of an all-weather road.

7.2.1 Designing a pavement

Rural roads provide connectivity to rural habitants and besides low-traffic volumes face other challenges, such as heavy rains, floods, and landslides in mountainous terrains. Thus, designing pavements properly to mitigate the effects of these challenges on rural roads is of paramount importance. As rural roads are not traffic intensive, facing major traffic only in the harvesting season, they cannot be built in the same way as highways. They have to be built to sustain harsh weather, while providing good riding quality and a lesser need for maintenance.

Rural roads are broadly classified in to two categories,which are defined by IRC: SP: 20 as:

- Other District Roads: 'Other district roads are the roads serving rural areas of production and providing them with outlet to market centres, *taluka* headquarters, block development headquarters or major district roads, and would serve to connect villages with population 1,000 and above or cluster of villages.'
- Village Roads: 'Village roads are roads connecting villages or cluster/group of villages with each other and to the nearest road of a higher category.'

Rural roads consist of following layers:

- Sub-grade
- Granular sub-base
- Base
- Pavement surface

The details of these layers have been discussed in Section 7.3

While designing a rural road, the following parameters are considered:

7.2.1.1 Traffic data

Like any other road, determining the possible traffic is important and, although in the case of rural roads traffic is less, it has a seasonal effect. Traffic during the harvesting season becomes very high as a number of vehicles loaded with farm and village produce travel from the villages to the nearby markets using these roads. IRC: SP: 72 lay down the guidelines for the collection and estimation of traffic data. Chapter 5 of IRC: SP: 20 describes the designing process of rural roads. Traffic data is used to determine the surface (Table 18) and thickness of rural roads (Figure 36) (Indian Roads Congress, 2002).

7.2.1.2 California Bearing Ratio

The CBR value of the subgrade (the surface on which the pavement will rest) is pivotal for the construction of the subsequent layers of the pavement. Road damages, such as rutting and depression in the pavement are caused due to poor strength of the subgrade. CBR is used to determine the thickness of rural roads (Indian Roads Congress, 2002).

7.2.1.3 Rainfall data

Heavy rainfall is the major reason for the erosion of rural roads and so the PMGSY guidelines clearly state the construction of all-weather roads. For the roads to be resilient to rainfall, surface dressing of various grades has been included for the ease of the engineer. Figure 36 explains the relationship of CBR and traffic on the pavement thickness. There the four lines, i.e. A, B, C, and D corresponding to different traffic flow intervals mentioned in terms of commercial vehicles per day (CVPD); after estimating the CBR value, we can determine the thickness of the pavement using the following graph.

Table 18 Matrix showing the surface properties of rural roads recommended for various intensities of rainfall and traffic

Rainfall (mm)	Surfacing of Rural Roads		
1500+	Thin bituminous surfacing (2-coats S.D.)	Thin bituminous surfacing (PMC + Seal Coat)	Thin bituminous surfacing (PMC + Seal Coat)
1000–1500	Single-coat surface dressing	Thin bituminous surfacing (2-coats S.D.)	Thin bituminous surfacing (PMC + Seal Coat)
500–1000	Unsealed surface (gravel stone)	Unsealed surface (gravel stone)	Thin bituminous surfacing (2-coats S.D.)
0–500	Unsealed surface (gravel stone)	Unsealed surface (gravel stone)	Thin bituminous surfacing (2-coats S.D.)
Traffic per day	0–50	50–150	150+

Source: Indian Roads Congress, 2002

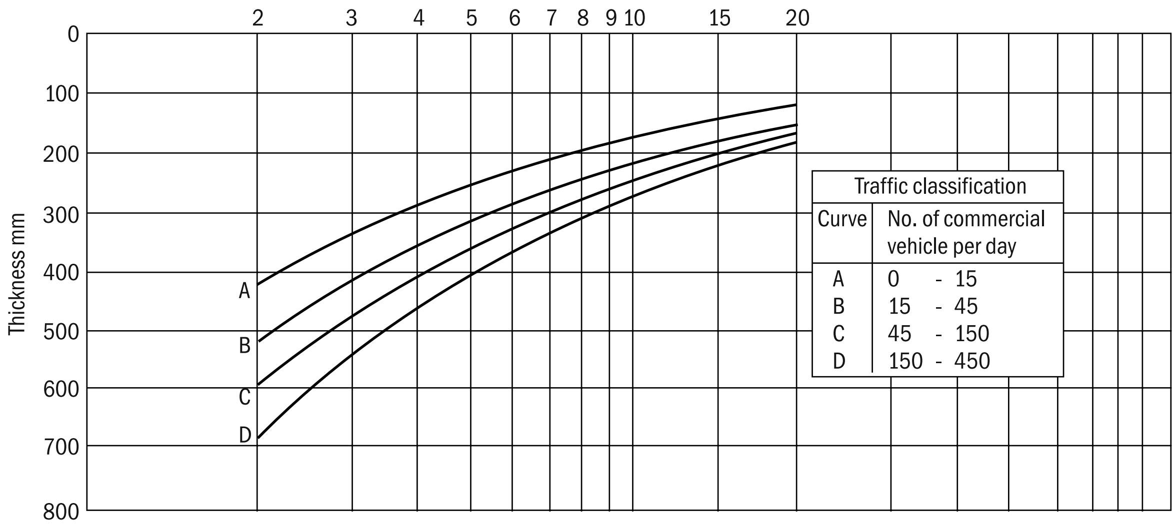


Figure 36 Graph showing the relation between traffic, CBR, and the thickness of pavement

Source: (Indian Roads Congress, 2002)

7.3 Materials Used for the Construction of Pavements

Commonly used materials for the construction of a rural road are soil, mineral aggregates, bituminous binders, and stabilizers, such as lime, cement, water, etc. where mineral aggregates constitute the major part of the pavement. For the economical construction of any pavement, it is important to be aware of the basic materials available near the construction site and to have a clear understanding of the soil on which the pavement is to be constructed. Materials used in the structural layers of the pavement should be selected based on these criteria and based on the availability, cost, and previous experiences. Use of locally available materials and recycling makes the construction economically efficient, and the road environmental friendly. The following section provides an overview of the layers and materials used in the construction of rural roads:

7.3.1 Subgrade

In rural roads, the top 30 cm of the cutting is considered as the subgrade. As per IRC:SP:20-2002, a minimum of 100% compaction for 30 cm of the subgrade is required. For the construction of subgrade, embankment, and earthen shoulders, the materials used are soil, gravel, moorum, or a mixture of these materials (Indian Roads Congress, 2002).

7.3.2 Granular Sub-Base

The main purpose of the preparation of this layer is to distribute the stress developed by the traffic over the

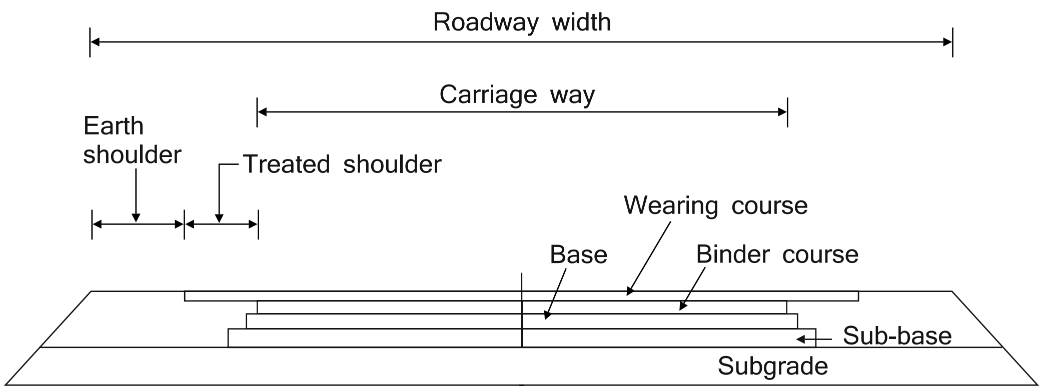


Figure 37 Cross section of rural roads

Source: IIT Kanpur

pavement on to the subgrade below it. The secondary purpose of the layer is to prevent the mixing of the soil in the subgrade with that of the base layer. Generally, prepared from locally available materials, low in terms of strength, the sub-base is usually made of moorum, natural sand, gravel, crushed slag, crushed stones, crushed concrete, granulated slag, brick metal and *kankar*, etc. (Indian Roads Congress, 2002).

7.3.3 Base

Base layer or Water Bound Macadam, as it is commonly known, comprises either crushed or broken stone, crushed slag, over-burnt aggregates, or naturally occurring aggregates, such as *kankar* and laterite. This layer is subjected to heavy stress from the traffic and is sometimes treated as wear course in desert location, where there is scanty rainfall (Indian Roads Congress, 2002).

7.3.4 Pavement surface

There are different types of pavement surface but for the construction of rural roads, the most common one is the flexible pavement. Flexible pavement design is done by calculating the CBR value and the determination of traffic. CBR charts are available through which the acceptable pavement thickness is chosen.

The surfacing of flexible pavements is done with bitumen. 'Bitumen is a viscous liquid, semi-solid or solid material, colour varying from black to dark brown, having adhesive properties, consisting essentially of hydrocarbons derived from distillation of petroleum crude or natural asphalt and soluble in carbon disulphide' (Indian Roads Congress, 2002). Since bitumen is a semi-solid material, it is essential to make it liquid to improve its workability; this is mostly done through adding kerosene and other petroleum products while heating it at high temperature (Indian Roads Congress, 2014). In other cases, emulsification of bitumen is done to make it workable at room temperature. The following section describes the technologies used to prepare the bituminous surfaces:

7.3.4.1 Hot mix

Developed in 1870, hot mix technology was fairly simple in those times involving drying, screening, proportioning, and mixing processes (Indian Roads Congress, 2010). With the advancement in technology, these simple techniques improved with addition of aggregate bins, cold elevators, rotary dryers, hot elevators, bitumen tanks, and mixing platforms. It is the most extensively used technique for the production of bituminous aggregates. Recently, due to the increasing awareness about climate change, hot mix technology—due to its high-energy consumption and high greenhouse gas (GHG) emissions—has come into question (Indian Roads Congress, 2002).

7.3.4.2 Warm mix

Patented in the USA first in 1956, and later purchased by Mobil Oil, Australia, in 1968, the technology found its eminence as an energy efficient solution (Muthen, 1998). The technology involves the addition of additives at a later stage of the heating of the bitumen, making it workable at a temperature lower than that of the hot mix technology (about 30 °C lower) (Indian Roads Congress, 2002).

7.3.4.3 Half-warm mix

The development of foamed bitumen in 1957 led to the synthesis of a technique that used heating of aggregates at 100 °C to achieve better binding capacity of the binder even for larger aggregates. The technology found its importance as it was more energy efficient than its predecessor, the warm-mix technology, in terms of its working temperature which is between 80–90 °C (Indian Roads Congress, 2002).

7.3.4.4 Cold mix

The most widespread method of rural road construction is the one in which the aggregates and bitumen is heated up to 150 °C. In this technology, it is very important to maintain the desired temperature at every stage. Failing to maintain these temperatures could affect the durability of the pavement. High rainfall, high altitude, cold weather conditions, long distance between hot mix plant and project site, are some of the challenges faced during the construction of pavements. Cold mix technology addresses all these problems. It is made up of cationic tailor-made cold mix binder that allows construction in all seasons.

The technology came into existence in the early 1900s and its application, as a pavement, was first started in the 1920s. In India, the use of cold mix first started in the 1970s, by that time the world had started using it in various fields of construction and maintenance of roads. In the year when India consumed only 20,000 tonnes, the whole world consumed about 12 million tonnes. Bitumen emulsion makes it possible for mixing and laying down the pavement at ambient temperature making it a viable technology (Indian Roads Congress, 2014).

It should be noted that this study focuses only on hot mix and cold mix technologies, which have been described at length in the following section.

Materials for the preparation of the premix and the seal coat for both the technologies have been described in Table 19 to Table 22.

Table 19 The aggregate size and quantity for premix carpet

Quantity of Aggregate for Premix Carpet	
Aggregate size	Quantity for 10 m² of road surface
Coarse aggregates- Normal size 13.2 mm (passing IS: 22.4 mm square mesh sieve and retained on IS: 11.2 mm square mesh sieve)	0.18 m^3
Coarse aggregates- Normal size 11.2 mm (passing IS: 13.2 mm square mesh sieve and retained on 5.6 mm square mesh IS sieve)	0.09 m^3
Total quantity of aggregates	0.27 m^3

Source: (Indian Roads Congress, 2004)

Table 20 The aggregate size and quantity for seal coat

Quantity of Aggregates for Seal Coat		
Type of seal coat	Aggregate size	Quantity for 10 m² of road surface
A	Coarse aggregates- 6.7 mm size (passing IS: 11.2 mm square mesh sieve and retained on IS: 2.8 mm square mesh sieve)	0.09 m^3
B	Fine aggregates- Medium coarse sand (fineness modulus of more than 2.5) or fine grit (passing IS Sieve No. 2.36 mm and retained on IS Sieve No. 180 microns)	0.06 m3

Source: Indian Roads Congress, 2004

While both the technologies use the same size and quantity of aggregates for both the premix and the seal coat as shown in Table 19 and Table 20, there is a difference in the method of preparation of these layers. The hot mix technology uses modified bitumen; the cold mix technology uses tailor-made cold mix binder. The comparison of the quantities of both the technologies for both the layers is provided in Table 21 and Table 22.

Table 21 Quantity of bitumen for premix carpet

Item	Quantity per 10m² Area of Road Surface	
	Hot mix	Cold mix
For 13.2 mm size coarse aggregates	9.5 kg	13-15 kg (MS)
For 11.2 mm size coarse aggregates	5.1 kg	6-7 kg (MS)

Source: Indian Roads Congress, 2004

Table 22 Quantity of bitumen used for seal coat

Type of Seal Coat	Quantity per 10m² Area of Road Surface	
	Hot mix	Cold mix
Type 'A' (Liquid Seal Coat)	9.8 kg	12 to 14 kg (RS)
Type 'B' (Premixed Seal Coat)	6.8 kg	10 to 12 kg (SS)

Source: Indian Roads Congress, 2004

7.3.5 Pavement construction

The hot mix technology involves heating the bitumen and the aggregates at high temperature and mixing them together; however, the cold mix technology has no such heating process involved in the construction of the pavement. The method of construction of pavement for both the technologies is summarized below.

7.3.5.1 Hot mix

After a proper cleaning of the site for dust particles and preparing the surface for laying, the tack coat is applied first (20–70°C) and left to cure for some time. Then the premix is prepared with the quantities mentioned in Table 19, following the temperature requirements mentioned in Table 23 according to the grade of bitumen chosen for the construction of the road. The bitumen is heated in the boiler at the desired temperature and the mixing of the aggregates is done, off-site, at the hot mix plant. The temperature difference between the aggregates and the bitumen should not be more than 150°C. After the laying of the premix using the paver (about 20–25m), rolling is done with 8–10 tonne smooth wheeled tandem roller. As soon as the paved surface reaches the desired temperature, a Seal Coat (Type A) is applied at the same temperature as that of the paving surface and smoothened with the help of an 8–10 tonne static weight vibratory roller or a simple 8–10 tonne smooth-wheeled tandem roller. Subsequently, the seal coat (Type B) is prepared as per the quantities mentioned in Table 22 and Table 20, for hot mix technology, and mixed with each other at the desired temperature, depending upon the grade of bitumen used, mentioned in Table 23. Lastly, the surface is rolled with an 8–10 tonne smooth-wheeled tandem roller and is left to dry before opening to traffic.

7.3.5.2 Cold mix

Firstly, the surface should be dirt and dust free, loose materials, if any, should be removed. For the preparation of a premix carpet, a cationic tailor-made cold mix binder of MS grade is used along with the quantities mentioned in Table 19 and Table 21.This premix carpet should be laid when the tack coat applied after cleaning turns black from brown. The aggregate quantity mentioned in Table 19 is charged in a hot mix plant without the heating arrangement. An appropriate amount of tailor-made cold mix emulsion is added as directed by the engineer-in-charge. Water is added to achieve the optimum water content of 1% by weight of aggregate. The tailor-made cold mix emulsion is added in the required quantity as mentioned in Table 21 and mixed for two minutes. After this, the premix is spread across the pavement till a thickness of 30 mm is achieved. Further, a wheel-tandem roller of 8–10 tonnes is used for compaction. Seal coat is applied 4–6 hours after laying the cold mix.

Table 24 shows the major differences in hot mix and cold mix technology in brief

7.4 Use of Recycled Products

Recycled materials used for road construction have been described in the following sections.

7.4.1 Reclaimed Asphalt Pavement

The bituminous pavement rehabilitation alternatives are mainly overlaying, recycling, and reconstruction.

Table 23 Temperatures of materials at various stages

Bitumen penetration (mm)	Range of Temperature in °C				
			Mixed material at		
	Bitumen mixing	Aggregate mixing	Discharge	Laying site	Rolling
30–40	160–170	160–175	170 Maximum	130 Minimum	100 Minimum
60–70	150–165	150–170	165 Maximum	125 Minimum	90 Minimum
80–100	140–160	140–165	155 Maximum	115 Minimum	80 Minimum
Modified bitumen	165–185	155–175	160 Maximum	130 Minimum	115 Minimum

Source: Indian Roads Congress, 2004

Table 24 Difference in hot mix and cold mix technology

Hot Mix	Cold Mix
High level of noise and air pollution	It controls air pollution
Emission of greenhouse gases	Heating of binder and aggregates is eliminated
The quality of bitumen gets affected during heating.	The thermal oxidative hardening of bitumen is checked, thus increasing the service life of the pavement
High-energy consumption	It is energy efficient and saves bitumen
Unsafe for the maintenance crew	Ease in handling and laying of road surface, thus increasing the work output

Source: Indian Roads Congress, 2004 and TERI analysis

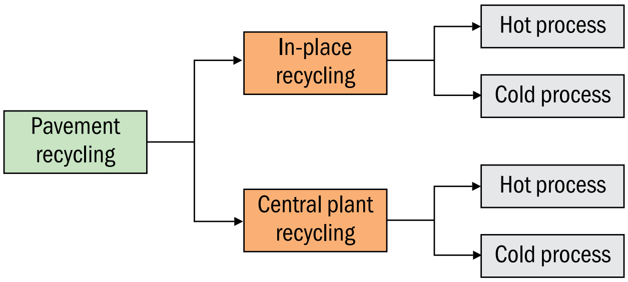


Figure 38 Classification of pavement recycling

Source: Das, 2005

'In the recycling process the material from deteriorated pavement, known as reclaimed asphalt pavement (RAP), is partially or fully reused in fresh construction' (Das, 2005). Here recycling methods can be broadly classified as central plant recycling and *in-situ* recycling. The following flow chart points out the different types of recycling methods.

7.4.1.1 Hot in-place recycling

Initially the pavement intended to be recycled is heated to a higher temperature using a suitable heating arrangement. This facilitates an easier removal of materials. After heating, the pavement surface is scarified to the required depth. Further, depending on the requirement, fresh aggregate and binder are added. The material is mixed well and compacted to the required thickness. As this process consumes less time, least disruption to traffic is caused. Also the transportation cost is less, as materials need not be taken away. The machinery required for this purpose, due to its bulky nature, sufficient right of way is required. This becomes an important consideration for in-place recycling within city areas

7.4.1.2 Cold in-place recycling

In cold in-place recycling process, first, the pavement is scarified. The scarified material is crushed to the required gradation. Then the required amount of fresh aggregates and binder in cold form (emulsion or cutback) are added. The mix is compacted and left for aeration. During this process, additives, such as cement, quick lime, and fly ash may be used. The cold mix recycling takes care of local geometric correction, correction of pavement distresses such as surface cracks. Being an *in-situ* process, the hauling cost is considerably low. The air quality-related problems during construction are almost negligible as compared to hot mix process. Similar to the hot in-place recycling process, the machinery required is bulky; hence sufficient manoeuvring space should be available for operating the equipment. Also, the lane needs to be closed for certain time so that sufficient time is available for curing of the freshly laid course. Moisture content (when bitumen emulsion is used) needs to be given importance as it influences gradation control, mixing, and, to a large extent, the workability of a recycled mix.

7.4.1.3 Hot central plant recycling

In this process, RAP is combined with the required quantity of bituminous binder and fresh aggregates in a hot mix plant. The resultant mix is heated to an elevated temperature and mixed thoroughly. The hot mix is transported to a paving site; it is then placed and compacted to the required compaction level. The main advantage of this process is that the mix properties and performance are comparable to that of virgin mix. The quality control in this process is better when it is compared to hot in-place recycling. As RAP is susceptible to moisture, care needs to be taken while storing it. Less workspace is required for laying the recycle mix; hence this is suitable for roads where the right of way is somewhat restricted. The RAP should not be exposed to extremely high temperature as it causes pollution due to smoke.

7.4.1.4 Cold central plant recycling

This process is similar to hot central plant mixing, except it does not involve any heating, and, therefore, emulsion bitumen is used as binder in most of the cases. Precise control on the mixing time is important; over-mixing may cause premature breaking of emulsified bitumen and, under-mixing may result in insufficient coating of aggregates.

7.4.2 Plastic waste

Plastic is rich in polymers. It is used as a stabilizing agent for soil and subgrade. It is also added to aggregates in hot mix asphalt pavement. Adding plastic to hot mix asphalt pavement improves the stripping resistance of the pavement.

7.4.3 Recycled asphalt shingles

Asphalt shingles are used as roofing materials. They are of two types: fibreglass asphalt shingle and organic asphalt shingle. These are mainly used in cement asphalt pavement. 'The quantity of asphalt shingle added to asphalt should not exceed more than 5% of the weight of asphalt. It is also use in cold mix patch repairing' (Byrne, 2005).

7.4.4 Crumb rubber

Using crumb rubber in pavement improves skidding resistance and shear strength. It also provides better durability in extreme weather conditions. For hot mix, it is generally added up to 30% of the mass of asphalt. And in cold mix, it is added up to 2% by mass of asphalt with fly ash up to 10% by mass of asphalt (M Hossain, 2010).

7.4.5 Foundry sand

It is a by-product of metal-casting industries. Foundry sand is fine grained with high silica content. They are generally used as filling material for base and sub-base. Due to environmental concerns related to this waste material, it is not extensively used.

7.4.6 Coal combustion by-products

Materials such as fly ash, boiler slag, furnace-bottom slag, vitrified ash, etc. fall under this category. Fly ash is the most commonly used by-product. While fly ash has various uses, it is mainly used as a stabilizing agent. Boiler slag provides resistance to skidding due to its angular glass surface. Furnace bottom ash is similar to fly ash but literature on this topic suggests that fly ash is preferred to furnace bottom ash. Pond Ash is slurry of water and ash dumped at lagoons. It is used with lime and fibre glass to enhance the properties of the pavement. Using pond ash improves the stiffness of the pavement.

7.5 Life Cycle Assessment

7.5.1 Introduction

Life cycle assessment (LCA) is defined as '[a] compilation and evaluation of inputs and outputs and the potential environmental impacts of a product system throughout its life cycle' (World Bank 2010). The main aim of life cycle assessment is to reduce the pollutants from being formed (World Bank 2010). Understanding LCA reduces the risk of deriving temporary solutions that that tend to shift the environmental problem from one place to the other. LCA identifies the impacts and environmental aspects related to the product's entire life, that is, 'cradle to grave'.

7.5.2 History

LCA had a very humble beginning in the 1960s, when concerns on the limitations of raw materials and energy were pointed out. 'In one of the first publications of its kind, Harold Smith reported his calculation of cumulative energy requirements for the production of chemical intermediates and products at the World Energy Conference in 1963' (SAIC, May 2006). In 1969, there was a study carried out by The Coca-Cola Company named 'Resource consumption and environmental release associated with beverage containers'; 1970–1990 was a period of development of the LCA. In this period, lots of approaches were developed that had a common theoretical backbone. In the 1980s, the concept of LCA was booming in every direction and sector. It was used by corporate firms as a marketing tool. It was in this period that life cycle costing models were introduced. In 1984, the Swiss Federal Laboratory for Material Testing and Research published a report which gave a comprehensive list of data required for LCA.

Since there were a lot of methodologies to conduct LCA, results were different even when the subject of the study was the same. Therefore, in 1990–2000 attempts were made to standardize the whole process. The idea of LCA gained pace in 1992 when a UN summit encouraged "cradle to grave" approach as the most promising tool for environment management. In the early 1990s, the North American and European branches of Society of Environment Toxicology and Chemistry (SETAC) took the initiative to bring together LCA researchers and practitioners and conducted co-ordinated activities, such as workshops and seminars (JeroenbGuin´Ee, 2007). As a result of these activities, SETAC released the 'Code of Practice for LCA', which was the first step taken in the direction of international standards. In 1994, the International Organisation for Standardisation (ISO) took the responsibility of laying down the standard methods and procedures for carrying out LCA. There are currently two international standards:

- ISO – 14040 (2006 E): This document elaborates the principles and broad framework used for LCA
- ISO – 14044 (2006 E): This document elaborates the guidelines and requirements for LCA

7.5.3 Some studies related to life cycle cost analysis

7.5.3.1 Methodology for estimating carbon footprint of road projects, case study: India

This study aims to estimate the carbon footprint of ADB-funded road construction and/or improvement projects in India to come up with a comprehensive approach for calculating the carbon footprint starting from the road construction phase through the operation and maintenance phase. This study states that the total carbon footprint of all ADB-funded projects in 2008 was 10.98 million tonnes (ADB, 2010). This carbon footprint was estimated for one year.

7.5.3.2 Life cycle analysis of transport modes

This study aimed to estimate the energy and CO_2 emissions impact of transport infrastructure for all its life stages: construction, operations, and maintenance. The study selected five types of transport infrastructure: National Highways (NH), long-distance rail, urban roads, Bus Rapid Transit System, and the metro rail system. The results of this study show that an understanding of the full life cycle energy and CO_2 impacts of transport modes can help choose modes or suggest inter-modal shift towards modes that are least energy and carbon intensive throughout their lives. In addition to the choice of mode or promoting a modal shift towards 'greener' modes, LCA can also help in intra-mode greening as it helps in understanding the share of various components that contribute to energy consumption and CO_2 emissions, thereby helping in identifying the appropriate mitigation measures.

7.5.3.3 Reduction of Carbon Footprint in Highways Sector

The study aims to identify the carbon-reduction potential of the highways sector through estimating carbon footprints, accruing from different typologies of highways, during different phases of highway development and operation. The study would aim to identify interventions to enhance climate resilience of the highways sector in India. The study would also determine the cost implication of the proposed carbon reduction and climate resilience interventions. The larger aim of the study would be to mainstream strategies that would enable actions, those required for developing low-carbon and climate-resilient highways, to dovetail into the existing policy and implementation framework of the country.

7.5.3.4 Life cycle cost assessment: TERI Approach

The environmental impacts due to the transport sector are not related to merely to the tailpipe. There are impacts for all life stages of the project, both direct and indirect. The LCA framework used by TERI is in line with ISO 14000. It considers a bottom-up approach, wherein, after defining the system boundary, LCA is applied to specific projects by carrying out extensive data collection. TERI has developed an India-specific spread sheet model to carry out LCA. For projects in India, the various components of LCA in the construction phase as considered in TERI's LCA model are:

1. Embodied energy and CO_2 of construction materials
2. Direct CO_2 due to fuel consumption by vehicles transporting construction materials
3. Direct CO_2 due to on-site fuel consumption (by construction machinery)
4. Embodied energy and CO_2 of fuel used (by construction machinery)
5. Vegetation removal - CS potential lost
6. Vegetation removal - use of some portion of removed trees as fuel wood

LCA for highway corridor for maintenance purposes was done under two main heads, that is, periodic maintenance and annual routine maintenance. Here, the embodied energy and carbon emissions were estimated for the quantity of materials used for the maintenance activities.

7.6 Maintenance of Rural Roads

Maintenance is defined as 'routine work performed to upkeep pavement, shoulders and other facilities provided for road users, as nearly as possible in their constructed conditions under normal conditions of traffic and forces of nature' (IRC: SP: 20, 2002).[1]

Maintenance is considered 'essential to get optimum service from the pavement structure during its life period' (IRC: SP: 20, 2002).

Maintenance is important because:[2]

- It safeguards the previous investments done in the construction phase by prolonging the life of the road and by reducing the rate of deterioration, construction, and rehabilitation
- It reduces the roughness of the roads and, in doing so, lowers the cost of operation of vehicles plying on the road
- Regular maintenance ensures reliable and continuous transport services by keeping the road open for traffic
- Regular maintenance sustains social and economic benefits of improved road access
- Maintenance for rural roads also generates local employment opportunities and additional market prospects for the local construction industry

7.6.1 Types of maintenance[3]

There are four categories of maintenance and these are as follows:

7.6.1.1 Routine maintenance

Routine maintenance is a cyclic/reactive activity that is performed on a regular basis throughout the year. It consists of both off-carriageway and on-carriageway activities. 'Routine maintenance activities are usually small-scale, widely dispersed, and often performed using manual labour'(International Labour Organisation, 2014).

Most common routine maintenance activities are as follows:

- Filling potholes, patching surface, and repair edges of pavement
- Repair shoulders and side slopes
- Clear drains, allowing free passage of water

1 http://pmgsy.nic.in/circulars/maintenance_framework.pdf.; last accessed August 17, 2017.

2 http://pmgsy.nic.in/GN_GMMR_2014.pdf; last accessed August 17, 2017.

3 http://pmgsy.nic.in/circulars/maintenance_framework.pdf; last accessed August 17, 2017

Table 25 Periodicity of routine maintenance activities

S. No.	Name of Item	Frequency of Operation in a Year
1	Clearing of roadside gutters	Twice
2	Pothole filling	Once
3	Filling up edges of asphalt surface of excavation borrow pit	(i) Single lane (a) T.I.* 0–1,000 - Twice (b) T.I. 1,000–5,000 - Four times (ii) One and Half lane (a)T.I. 1,000–5,000 - Twice (b)T.I. Over 5,000 - Four times (iii) Two lane (a)T.I. 1,000–5,000 - Once (b)T.I. Over 5,000 - Twice
4	Dressing of beams	Once
5	Whitewashing guard stones	Twice
6	Fixing disturbed caution board/village name board/ speed limit board, etc.	Once
7	Re-fixing displaced guard stones	Once
8	White washing and geroo painting of trunks of trees	Once
9	Cutting of branches of trees, etc.	Once
10	Topping of WBM blindage operation including picking of loose metal	18 times
11	Maintenance of catch water drains	Once
12	Clearance of cross drainage works	
13	Clearing of wild seasonal growth on berms	Once
14	White washing parapets of cross drainage works	Once
15	Earthwork in berms, de-silting of drains, etc.	As per requirement

* T.I denotes traffic intensity in tonnes per day

Source: (IRC:SP:20, 2002)

- Clear culverts and other water crossings
- Remove debris from roadway and drains
- Cut grass and bushes
- Maintain road signage and pavement markings

7.6.1.2 Periodic maintenance

Periodic maintenance refers to the renewal of road surface. In the case of rural roads, periodic maintenance may be required at an interval of 5 to 6 years, depending on the initial construction standards and quality, traffic, and weathering effect. The work involved is usually larger and requires more equipment and specialized skills. As a result, this work is considerably more costly than routine works. It is seen that 'if routine maintenance is regularly carried out, particularly attending to timely patchwork on the pavement, maintenance of camber/super elevation and side drains, the requirement of periodic maintenance can be postponed' (International Labour Organization, 2014).

Based on the experience in the country, the following specifications are suggested for periodical renewals of rural roads:

- Single-coat or two-coat surface dressing as per IRC: 17
- 20 mm-thick premix carpet with seal coat as per IRC: 14
- Mix-seal surfacing as per Clause 508 of MoRTH specifications

The specifications and thickness of the renewal course should be such that the road surface is restored close to its original condition as far as possible. The following broad guidelines are recommended for the type and periodicity of renewals as given in Table 26.

7.6.1.3 Special repairs

Special repairs are necessary when road structures, such as culverts and bridges have suffered serious distress and damage and require major repairs/replacement. Major repairs of protective works, such as breast walls, retaining walls are also treated as special repairs.

7.6.1.4 Emergency works

This is required when unforeseen events occur, such as landslides, floods, earthquakes, etc. The immediate requirement is to reopen the safe passage on the rural road and subsequently plan for and provide for restoring the road to its former or better condition.

Table 26 Type and periodicity of renewals

Traffic (CVPD)	Low Rainfall (1500mm/year)	Medium Rainfall (1500-3000 mm/year)	High Rainfall (>3000 mm/year)
<150	Surface dressing : 6 years	Surface dressing : 6 years	Surface dressing : 6 years
150–450	Surface dressing : 5 years	Surface dressing : 4 years	Surface dressing : 3 years
>450	Open graded premix carpet :6 years	Open graded premix carpet :5 years	Open graded premix carpet :4 years

Source: IRC: SP: 20, 2002

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9 Annexures

9.1 Life Cycle Assessment Methodologies

Table A1 Summary of life cycle estimation methodologies for roads developed/used in other studies (international and national studies)

Study	Author/s and year of study	LCA approach
International Studies		
Life cycle assessment of roads - A pilot study for inventory analysis	Håkan Stripple (2001)	The study covers all the phases of road's life cycle, i.e., construction, maintenance, and operations (except emissions from traffic). It includes emissions from sourcing/production of raw materials to consumption and recycling of materials
Life cycle assessment of road construction	Ulla-Maija Mroueh, et al. (2001)	The study assesses life cycle impact procedures for comparison and evaluation of alternative road and earth constructions
Hybrid life cycle inventory for road construction and use	Graham J. Treloar, et al. (2004)	The hybrid LCA approach is used to estimate environmental impact not only during construction phase but also during operations phase, including manufacture, use, and maintenance of vehicles using the road
Life cycle analysis and decision aiding: An example for roads evaluation	Chabane Mazri, et al. (2004)	The LCA study focuses on environmental impact during the three phases, namely deconstruction, material sourcing, and construction
Life cycle assessment model for road construction and use of residues from waste incineration	Harpa Birgisdóttir (2005)	The LCA study evaluates the environmental impact of using waste materials as well as compares the impact of disposing wastes at landfill sites and using it for road construction
Life cycle assessment of pavements: A critical review of existing literature and research	Nicholas Santero, et al. (2010)	The study critically analyses past LCA of pavements. It focuses on presenting various methods of LCA implementation, along with describing the different types of LCA applied in each research. The study does an exhaustive analysis of each pavement LCA
GHG calculation for highway construction using a hybrid life cycle assessment approach	Darrel Cass and Amlan Mukherjee (2011)	The study includes material acquisition, manufacturing, construction, and usage phase of the life of the pavement in life cycle analysis of highway construction
The greenhouse gas emission from Portland cement concrete pavement construction in China	Feng Ma (2016)	The study involves estimating carbon emissions using life cycle inventory method for roads constructed using Portland cement. Emissions estimation is limited to the construction phase only and does not include maintenance and operation phases
India Studies		
Methodology for estimating carbon footprint of road projects: Case study	ADB (2010)	The study estimates direct and indirect CO_2 emissions under the three phases – road construction, road operations and road maintenance

Indian Studies		
Life cycle analysis of transport modes	TERI (2012)	The study uses the LCA methodology to estimate life cycle energy consumption and CO_2 emission values for the different modes of transport, including highways/roads
Estimation of carbon footprints of bituminous road construction process	Siksha Swaroopa Kar, et al. (2015)	The study calculates the CO_2 emissions released during warm mix asphalt and cold mix asphalt methods of road construction

Source: Compiled by TERI

9.2 Sampling and Analysis for Measuring Air Quality

PM_{10} sampler (Model 550; Envirotech Pvt Ltd, India) was used to measure the ambient concentrations of PM_{10} with the average flow rate of 16.6 L/min. The replicates were maintained at each site to reduce instrumental error in measurement. The instruments were operated for 24-hour at each site. The instrument has the provision for incorporation of a gaseous sampling unit for simultaneously measuring gaseous pollutants, such as NO_x. Gas samples are bubbled through the absorbing media in a glass impinger at a flow rate of 0.5 L/min using the gaseous sampling attachment in the PM_{10} sampler.

Pre-conditioned and pre-weighed glass micro fibre filters of 47 mm diameter (Whatman®, United Kingdom) were used for collection of PM_{10}. The filter papers were transferred to vacuum desiccators before and after completion of sampling and desiccated for 24 hours to a constant weight. After desiccation, the filter papers were weighed for post-exposure weight using a microbalance with an accuracy of 1 μg. The ambient concentration of PM_{10} was estimated from the difference in the weight of the filter and the volume of air sampled during the 24-hour sampling period.

Concentration of NO_x was analysed by wet chemical method (IS 5182 [part 6]: 2006). Nitrogen dioxides samples were collected by bubbling air through a solution of sodium hydroxide and sodium arsenite at a constant flow rate of 0.5 L/min. The concentration is then determined calorimetrically.

CO was measured at 5-min intervals using a portable Q-track monitor (IAQ-Calc, Model 7545, TSI). The CO measurement range of the instrument was 0–500 ppm with ±3 ppm accuracy and 0.01 ppm resolution. Concentrations of VOC were measured with portable handheld compound-specific VOC monitor (Ultra RAE 3000 systems, USA). The VOC measurement range of the instrument was 50 ppb to 5,000 ppm with a resolution of 25 ppb. Annual calibrations of both instruments were performed by the respective manufacturer as per recommendation.

The methods followed were strictly in accordance with the guidelines laid down by Bureau of Indian Standards and Central Pollution Control Board (CPCB). The summary of sampling and monitoring technique is shown in Table 6.

Table A2 Summary of pollutant sampling and monitoring techniques

Pollutant	Sampling and measurement techniques
PM_{10}	Sampling by Fine Particulate Sampler (Envirotech Model-APM550) and analysis by gravimetric technique
NO_X	Absorption followed by analysis by wet chemical methods (Jacob & Hochheiser modified Sodium Arsenite method) IS 5182 (Part 6): 2006
VOCs	Portable handheld compound-specific VOC monitor (Ultra RAE 3000 systems, USA make)
CO	Q-track, TSI instrument

The analysed results of the ambient air quality monitoring were compared with the National Ambient Air Quality (NAAQ) standards prescribed by CPCB, wherever applicable.

The ambient concentrations of different air pollutants were reported after subtracting them from the concentrations in the respective background (control) location to understand the effect of the hot mix and cold mix technologies on the air quality during the construction of rural roads.

9.3 Material consumption

Table A3 Material consumption in sample rural road projects in Uttarakhand and Assam

Material Consumption	Unit	Uttarakhand		Assam	
		Hot mix	Cold mix	Hot mix	Cold mix
Phase 1					
Construction of 1 km of road					
Wearing course (pavement surface)					
Bitumen/cationic bitumen emulsion	Tonnes	10.54	10.71	14.00	20.00
Coarse aggregate	Tonnes	140.48	142.79	329.00	315.00
Fine aggregate	Tonnes	0.00	37.68	0.00	0.00
Total	Tonnes	151.01	191.18	343.00	335.00
Total road construction					
Coarse aggregate	Tonnes	2,937.33	2,555.92	3,908.00	3,299.00
Fine aggregate	Tonnes	304.04	200.69	3.00	0.00
Soil	Tonnes	0.00	0.00	1,259.00	1,362.00
RCC	Tonnes	0.00	0.00	14.00	0.00
Cement	Tonnes	46.63	21.55	25.00	1.00
Brick	Tonnes	0.00	0.00	4.06	7.00
Reinforcement	Tonnes	0.00	0.00	8.00	0.00
Bitumen/cationic bitumen emulsion	Tonnes	10.54	10.71	14.00	20.00
Diesel	Litres	2,090.52	1,611.33	2,170.00	2,186.00
Timber	Tonnes	16.00	0.00	0.00	0.00
Kerosene	Litres	0.00	0.00	583.00	0.00
Total	Tonnes	3,314.54	2,788.88	5,235.06	4,689.00
Maintenance of 1 km road					
Coarse aggregate	Tonnes	38.69	15.47	22.00	20.60
Bitumen/cationic bitumen emulsion	Tonnes	1.00	0.40	1.00	0.77
Cement	Tonnes	0.00	0.00	10.50	0.00
Soil	Tonnes	0.00	0.00	97.50	76.00
Diesel	Litres	0.00	46.00	83.00	42.00
Timber	Tonnes	0.60	0.00	0.00	0.00
Kerosene	Litres	0.00	0.00	17.00	4.00
Total	Tonnes	40.29	15.87	131.00	97.37

Material Consumption	Unit	Uttarakhand		Assam	
		Hot mix	Cold mix	Hot mix	Cold mix
Phase 2					
Construction of 1 km of road					
Wearing course (pavement surface)					
Bitumen/cationic bitumen emulsion	Tonnes	-	-	13.7	20.16
Coarse aggregate	Tonnes	-	-	216.00	335.62
Fine aggregate	Tonnes	-	-	0	0
Total	Tonnes	-	-	229.7	355.78
Total road construction					
Coarse aggregate	Tonnes	-	-	1,673.00	2,863.00
Fine aggregate	Tonnes	-	-	617	571
Soil	Tonnes	-	-	8,361.00	22,788.00
RCC	Tonnes	-	-	0	0
Cement	Tonnes	-	-	4.13	4.13
Brick	Tonnes	-	-	37.5	37.5
Reinforcement	Tonnes	-	-	0.30	0.30
Bitumen/cationic bitumen emulsion	Tonnes	-	-	13.7	20.16
Diesel	Litres	-	-	30,870.00	37,870.00
Timber	Tonnes	-	-	0	0
Kerosene	Litres	-	-	0	0
Total	Tonnes	-	-	10,706.63	26,284.09
Maintenance of 1 km road					
Routine maintenance					
Coarse aggregate	Tonnes	-	-	16.67	13.20
Fine aggregate	Tonnes	-	-	2.00	1.60
Bitumen/cationic bitumen emulsion	Tonnes	-	-	0.80	0.70
Cement	Tonnes	-	-	0.07	0.10
Soil	Tonnes	-	-	13.33	12.00
Diesel	Litres	-	-	70.00	0.00
Timber	Tonnes	-	-	0.00	0.00
Kerosene	Litres	-	-	0.00	0.00
Total	Tonnes			32.87	27.60
Periodic maintenance					
Bitumen	Tonnes	-	-	17.03	-
Coarse aggregate	Tonnes	-	-	451.46	-
Diesel	Litres	-	-	1260	-
Total	Tonnes			468.49	

Source: TERI *analysis*

9.4 Conversion Factors for Various Construction Materials

Table A4 Coefficients for calculation of embodied energy and CO_2 emissions

Material Used	Embodied Energy Coefficient (MJ/kg)	Embodied Carbon Coefficient (kg CO_2/kg)
Coarse aggregate	0.083	0.005
Fine aggregate	0.083	0.005
Soil	0.450	0.024
Cement	5.500	0.950
Brick	3.000	0.240
Reinforcement	20.100	1.460
Bitumen/cationic bitumen emulsion	51.000	0.550
Diesel	35.800	3.222
Timber	30.800	1.800
Kerosene	36.108	2.898

Source: Hammond and Jones (2011)

9.5 Transport of Materials

9.5.1 Uttarakhand

Table A5 Transport of materials in Uttarakhand

Construction Component	Source	Distance from Project Site (km)	Materials Transported	No. of Trips	Mode of Transport
Projects under construction					
Bajoon to Adhora MR (Stage 2) (hot mix)					
Earthwork and retaining walls	Local	0	Stone	0	Manual
	Haldwani	42	Sand, cement	153	Truck
Drainage	Local	0	Stone	0	Manual
	Haldwani	42	Sand, grit, cement	79	Truck
Base, sub-base, sub-grade	Local	8	GSB	859	Manual
	Haldwani	42	Grit	350	Truck
Wearing course	Haldwani	42	Emulsion (SS-1), Emulsion (RS-1), Bitument S-90, Grit	115	Truck
Road markings and traffic signs	Haldwani	42	Mild steel, cement, sand, grit	4	Tempo
Petsal–Bamanswal–Kapkot MR (cold mix)					
Earthwork and retaining walls	Local	0	Stone, sand	0	Manual
	Kathgodam	75	Cement	41	Truck
Drainage	Local	0	Stone, sand	0	Manual
	Kathgodam	75	Cement	25	Truck
Base, sub-base, sub-grade	Local	0	GSB, stone, grit	0	Manual

Construction Component	Source	Distance from Project Site (km)	Materials Transported	No. of Trips	Mode of Transport
Wearing course	Haldwani	78	Emulsion (SS-1), Emulsion (RS-1), Bitumen S-90, Grit	374	Truck
Road markings and traffic signs	Kathgodam	75	Mild steel, cement, sand, grit	7	Pick-up, truck
Projects under maintenance					
Daniya–Ara–Salphar MR (hot mix)					
Routine maintenance	Local	8	Stone grit	77	Truck
	Haldwani	146	Stone grit, lime	56	Truck
	Mathura refinery	484	Bitumen	3	Truck
Pahariyadhar to Surang MR (cold mix)					
Routine maintenance	Local	6	Stone grit	15	Truck
	Haldwani	80	Stone grit, lime	14	Truck
	Panipat refinery	400	Cold mix emulsion	1	Truck

Source: URRDA and TERI analysis

9.5.2 Assam

Table A6 Details of transport of materials in Assam

Construction Component	Source	Distance from Project Site (km)	Materials Transported	No. of Trips	Mode of Transport
Phase 1					
Projects under construction					
Ghoramari Buragaon to NH 52 (Hot mix)					
Earthwork and retaining walls	Buragaon	3	Soil	188	Truck
	1815 mile	42	RCC	2	Truck
Drainage	18th mile	45	Chips	87	Truck
	Khonamo	30	Bricks	1	Truck
	Tezpur	15	Reinforcement, cement	4	Truck
Base, sub-base, sub-grade	18th mile	45	GSB, metal	450	Truck
Wearing course	18th mile	45	Chips	49	Truck
	Guwahati	200	Emulsion (SS-1), Emulsion (RS-1), Bitumen S-90	5	Truck
Road markings and traffic signs	Tezpur	15	Mild steel, cement	30	Pick-up
	Khonamo	30	Sand, chips	60	Truck
Ghogra TE to NH 52 (cold mix)					
Earthwork and retaining walls	Ghoghra	3	Soil	510	Truck
Drainage	18th mile	45	Chips	87	Truck
	Khonamo	30	Bricks	1	Truck
	Tezpur	15	Reinforcement, cement	4	Truck

Construction Component	Source	Distance from Project Site (km)	Materials Transported	No. of Trips	Mode of Transport
Base, sub-base, sub-grade	18th mile	45	GSB, WBM	1,116	Truck
Wearing course	Guwahati	200	Emulsion (SS-1), Emulsion (RS-1), cold mix bitumen, grit	129	Truck
Road markings and traffic signs	Tezpur	15	Mild steel, cement	2	Pick-up
	Khonamo	30	Sand, chips	2	Truck
Projects under maintenance					
Gorhagi to Chalia road (hot mix)					
Routine maintenance	IOC Guwahati	242	Hot mix bitumen	1	Truck
	Rotuwa	20	Fine aggregate, cement	8	Truck
	B Chariali	4	Paint, polymer, water	3	Tanker
	Gorehagi	2	Soil	56	Tipper
Borpura to Rotuwa (cold mix)					
Routine maintenance	IOC Guwahati	262	Cold mix bitumen	4	Truck
	Rotuwa	1	Coarse aggregate, water, soil	401	Truck, Tanker, Tipper
	B Chariali	18	Paint, primer, diesel, kerosene	2	Tanker, Tipper
Phase 2					
Construction phase					
Niz-Chilabandha to Langichuk (hot mix)					
Earthwork and retaining walls	Local	0–1	Soil	410	Truck
Drainage	Local	0–1	Cement, brick	5	Tempo, truck
	Kathalguri	41	Sand	1	Truck
	Samaguri	35	HP pipe	2	Truck
Base, sub-base, sub-grade	Local	0–1	Soil	820	Truck
	Bagori quarry	36	GSB	130	Truck
	Kathalguri	41	Coarse aggregate	130	Truck
Wearing course	IOC Guwahati	180	Bitumen	4	Truck, tempo
	Kathalguri	41	Coarse aggregate	42	Truck
Road markings and traffic signs	Local	0–1	Iron, Cement, Sand, Coarse aggregate	1	Truck
Dhekial–Sarubhogia (cold mix)					
Earthwork and retaining walls	Local	0–1	Soil	1,560	Truck
Drainage	Local	0–1	Cement, brick	5	Tempo, Truck
	Kathalguri	41	Sand	1	Truck
	Samaguri	35	HP pipe	2	Truck
Base, sub-base, sub-grade	Local	0–1	Soil	718	Truck
	Bagori quarry	36	GSB	120	Truck

Construction Component	Source	Distance from Project Site (km)	Materials Transported	No. of Trips	Mode of Transport
	Kathalguri	41	Coarse aggregate	110	Truck
Wearing course	IOC Guwahati	180	Bitumen	4	Truck, Tempo
	Kathalguri	41	Coarse aggregate	42	Truck
Road markings and traffic signs	Local	0–1	Iron, cement, sand, coarse aggregate	1	Truck
Routine maintenance phase					
Niz-Chilabandha to Langichuk (hot mix)					
Routine maintenance	IOC Guwahati	180	Bitumen	1	Tempo
	Kathalguri	41	Coarse aggregate, fine aggregate	6	Truck, Tempo
	Local	0–1	Soil, Cement, Paint, Primer	3	Truck
Dhekial–Sarubhogia (cold mix)					
Routine maintenance	IOC Guwahati	180	Bitumen	1	Tempo
	Kathalguri	41	Coarse aggregate, fine aggregate	3	Truck, Tempo
	Local	0–1	Soil, cement, paint, primer	2	Truck
Periodic maintenance					
Niz-Chilabandha to Langichuk (hot mix)					
Periodic maintenance	18th mile	86	Coarse aggregate	59	Truck
	IOC Guwahati	180	Bitumen	3	Truck, Tempo

Source: *Assam PWD and TERI analysis*

9.6 Stakeholder Workshop

Minutes: Stakeholder Workshop on TERI's Study on the 'Life Cycle Assessment of Hot Mix and Cold Mix Technologies for Construction and Maintenance of Rural Roads'

Date: August 18, 2017

Time: 9:00 A.M. to 1:00 P.M.

Venue: Seminar Hall II, India International Centre, Max Mueller Marg, Lodhi Estate, New Delhi

The stakeholder workshop on the 'Life Cycle Assessment of Hot Mix and Cold Mix Technologies for Construction and Maintenance of Rurals Roads' was held on August 18, 2017. The workshop was jointly organized by the National Rural Road Development Agency (NRRDA), Ministry of Rural Development, Government of India, and TERI. The primary objective of the workshop was to discuss and disseminate the key findings of the study, in particular to deliberate on the potential of cold mix technologies in reducing the negative environment-related externalities of conventional rural road construction and maintenance technology i.e. hot mix technology. The agenda of the workshop is provided later along with the list of participants at the workshop. The discussions of the workshop are summarized in the following sections.

Welcome Address by Dr Ajay Mathur, Director General, TERI

In his welcome address, Dr Ajay Mathur introduced TERI as a premier research institution, focusing on policy and providing services that help society move towards sustainable development. Regarding the topic under discussion, he highlighted the importance of focusing on the costs and benefits of the two technologies (hot mix and cold mix technologies) in rural road construction and maintenance activities. Further, he emphasized on identifying which of the two technologies was more useful to NRRDA and other implementing agencies. He said that the primary motive of project was to acquire clarity in the decision-making process about use of the technology. He also mentioned that in the context of the present study, it was important to obtain answers to the following two questions:

- First, when should either of the two technologies be used for rural road construction
- Second, over the lifetime of the road, which of these technologies would be more appropriate for maintenance

Dr Mathur emphasized that in order to arrive at a decision, benefits of both the technologies would have to be considered and a life cycle assessment of the two would prove to be appropriate for the same. In addition to discussing the findings of the study, he hoped that the workshop would begin a dialogue on the process of implementation of these findings. He concluded by stating that he looked forward to the discussion and hoped that the presence of experts and policy makers would help in attaining a concrete understanding on the way forward.

Opening Remarks by Mr Rajesh Bhushan, Additional Secretary and Director General, National Rural Roads Development Agency

In his opening address, Mr Rajesh Bhushan stated that rural roads comprised 80% of the total road network in India and hence, it was crucial to construct and maintain high quality rural roads. Highlighting the importance of the workshop, he stated that those present at the workshop—field engineers, members of State Technical Agencies and Principal Technical Agencies, and members of the industry—were the key personnel responsible for developing and implementing such technologies. He further mentioned that rural roads are a means of rural poverty reduction and that it was the prerogative of the Ministry of Rural Development, Government of India, to provide cost effective and time saving construction techniques. He stated that under the Pradhan Mantri Gram Sadak Yojana (PMGSY), clean technologies, such as cold mix, are being given immense importance in the construction of rural roads. He specified that in the first fourteen years of the programme, only 800 km of roads had been constructed, while during the period 2014–2016, a road stretch of 2,000 km were constructed; the target for 2017 being 10,000 km. Mr Bhushan pointed out that while under PMGSY, about 35,000 km of roads are being added every year, roads constructed using innovative technologies account for only a fraction of this. Thus, there is a need to promote such technologies. The highlighted that in addition to lowering the carbon footprint, rural roads constructed through innovative and clean technologies can contribute to saving in time and cost, extending the working season, and reducing the risk to the health of the workers. Mr Bhushan reiterated the importance of the present study by stating that although the government has been encouraging states to adopt new technologies in rural road constructions and maintenance, there has not been any empirical study assessing the life cycle costs of these technologies. He mentioned that the Ministry would like to conduct more such studies on the use of other unconventional technologies, such as fly ash, geotextiles, soil stabilizers, and waste plastics. In addition to this, Mr Bhushan also said that since the study was a first-of-its-kind, it was limited in terms of the sample size, which in turn was indicative of the fact that very robust inferences could not be derived from the study. Hence, he concluded that the need of the hour was the formation of a multidisciplinary team, which could take on larger and broader studies. In order to facilitate the same, a multi-institutional approach needs to be adopted, with TERI playing the role of a nodal agency. Finally, he stated that the focus of forthcoming studies should also focuses on road deterioration different technologies. He hoped that the interaction would lead to a lively debate and suggestions, which could then be incorporated in the report and would further lead the way forward.

Opening Remarks by Mr S Vijay Kumar, Distinguished Fellow, TERI

Mr S Vijay Kumar, in his opening remarks, stated that although PMGSY began as a central intervention for poverty reduction, its primary objective has also been to motivate states to emulate the processes under PMGSY and implement these for all rural roads. He expected that this study would be able to demonstrate the processes applicable for all rural roads and guiding respective states on the process of using the same. He reasoned that it was not the construction of the roads but rather the maintenance of roads that facilitated poverty reduction. Hence, roads that could be maintained better are the solution and the role of technologies, such as cold mix, in the same. He also mentioned that the Online Management and Monitoring System of PMGSY should be further developed so that it is the only primary database for all future studies. Mr Vijay Kumar expressed his optimism at how the study already seemed to find a ready market in various states and hoped that the discussion would carve the way forward in the adoption of unconventional technologies.

Presentation of the Study by Ms Akshima Tejas Ghate, Senior Fellow and Associate Director, Transport and Urban Governance Division, Sustainable Habitat Programme, TERI

Discussion among speakers and participants

In his opening comments, Mr S Vijay Kumar said "when we look at rural roads we cannot propagate new technology just because it is new; we have to contextualize it to economy, efficiency, and technological development." He mentioned that due to the overuse of scarce materials, it is imperative to economize on their use. Rural roads constitute a large chunk, about 80%, of road network but account for only 20% of the traffic. Therefore, the kind of technology used should be contextualized at the design stage itself.

Mr Mahesh Hiremath, Director, NRRDA, mentioned that the sample size in the study was small. He specified that the cost difference between hot mix and cold mix is due to the frequency of periodic maintenance and it should be noted that strength-wise, both technologies provide similar results. He added that, specifications of cold mix technology are already a part of Schedule of Rates (SOR) in all states as it is included in Indian Roads Congress (IRC) codes. He added that possibilities of surface dressing by cold mix or waste plastic need to be explored.

Mr A V Rajesh, JD, NRRDA, enquired, that since the report recommends that selection of cold mix should be project/site specific, and it would be helpful if TERI could devise the possible parameters/criteria for site selection. Agreeing that it was a practical suggestion, Mr S Vijay Kumar said that the pre-decided criteria would enable faster approvals of the DPR via selection of various technologies, such as hot mix, cold mix, geo synthetic, waste plastic, etc.

Mr Hiremath pointed out that except hot regions like Rajasthan, cold mix is suitable everywhere. However, an official from BitChem added that recently, two roads in Hoshangabad district, Madhya Pradesh, have been constructed using cold mix technology where average temperature was 46°. The performance has been satisfactory so far.

Mr S Vijay Kumar recommended that there is a need to develop some kind of prioritization principles. If cold mix could be used in all conditions, then it leads to an axiom of choice with the contractor as to which technology to use and it is seen that the contractors will generally opt for the more traditional option (hot mix technology). He added that in the states where working period is low due to rainfall, cold season, etc., cold mix might be a better choice as its use enables carrying out work for longer periods.

Mr Mukesh Gupta, Chief Technical Advisor–Rural Roads, International Labour Organization (ILO), agreed that cold mix could perform wonders in the cold and rainy season. He specified how engineers are reluctant to adopt cold mix due to factors, such as entry of various new companies/brands in the manufacturing of cold mix emulsion that has raised concerns about the quality of emulsion. While the qualities of supplies from big companies are assured, for small companies, the quality of material cannot be guaranteed. The quality of the material also varied according to the batches of production. Some batches may be good and road users enjoy all benefits of cold mix while other batches may not be workable at all. In response, Mr Hiremath assured that NRRDA is taking up this issue under tripartite agreements with technology providers, especially under PMGSY.

Mr S Vijay Kumar specified that scaling up should not be carried out at a rapid pace. In fact, on the contrary, it should be completed in a manner such that quality is maintained. He added that prioritization and rational decision making should be undertaken to maintain quality.

Mr Ankur Hatibaruah, Head of Business Development, BitChem, informed the stakeholders that BitChem has introduced tripartite agreements where the onus is on the organization for any technology failures. Such agreements have been signed with state agencies of Uttar Pradesh, Sikkim, Odisha, Jharkhand, and Bihar. He also mentioned that BitChem has filed a joint patent with the Central Road Research Institute (CRRI) to build confidence amongst the state agencies.

Mr S Vijay Kumar further raised the point that in order to prioritize the advantages of cold mix, project implementations units (PIUs) may also actually prefer if there are state-level rate contracts with authorized agents and whoever operates these contracts will definitely incorporate quality checks and inspections of both manufacturer and destination supplies. If the matter is left to the PIUs and contractors, it will add to the risks of adopting cold mix. NRRDA can, thereafter, look into the practical aspect so that risks to PIUs are rationalized and quality constraints are properly applied. Mr Hiremath responded that PIUs must get the materials tested with state technical agencies (STAs) and not use it without testing, whether it is from BitChem, Hincol, IOC or any small supplier.

Thereafter, Mr S Vijay Kumar opened the discussion for the state agencies.

Mr A K Mondal, Chief Engineer, Panchayat and Rural Development Department (P&RD), West Bengal, stated that construction of 1,000 km road stretch has been sanctioned using cold mix in the state. Mr Santanu Ghosh, Executive Engineer, P&RD, West Bengal, recommended that suck study should also consider other social and environmental costs to make the results richer as the initial cost will definitely be higher for cold mix.

Mr P K Prasad, Executive Engineer, Rural Works, Odisha, stated that more than 30 km rural roads stretch using cold mix has been constructed in the state. Mr Anadi Charan Sahoo, Executive Engineer, Rural Works, Odisha, mentioned that his department has faced resistance from local people at site since they do not accept cold mix technology. He added that they have conducted various community participation programmes to mobilize society. He also mentioned that cold mix is easier to construct and the performance, so far, has been good as no potholes have developed in the concerned stretches during the past one year. Further, cold mix technology is being used in Odisha since the last 10 years for maintenance purposes.

Mr S Vijay Kumar explained that rural roads are close to the community/people and they understand the process of road construction. The people are resistant to changes and prefer roads to be constructed by hot mix (technology) rather than cold mix technology.

By convincing them that maintenance of rural roads using local community labour is easier under cold mix technology roads, people's support can be gained.

Mr Nabi Ahmad, Assistant Engineer, PWD, Bihar, enquired if waste plastic could be used in cold mix technology and surface dressing using this method can be carried out. Mr S Vijay Kumar expressed certain reservations regarding the use of waste plastic. He specified that it is more beneficial to use plastic waste in urban areas rather than in dispersed rural roads. This results from the demanding process of collection of the right kind of plastic waste, conversion of this waste into pellets, and finally its distribution to remote rural areas. To answer the question related to the use of plastic waste in surface dressing, he gave the example of Tamil Nadu where waste plastic was used to coat the chips. In order to coat the plastic on chips they were heated, and once chips are heated, cold mix could not be used. Mr Hiremath added how in Indore the municipality collects waste plastic and after shredding the waste, supplies the same to the contractors and PWD engineers in packets. Mr Hiremath specified that heating is needed to coat the coarse aggregate with plastic as it simplifies the bonding process with bitumen. Mr S Vijay Kumar further discussed that, in addition to heating, chips need to be washed, which makes it difficult to be used in the rural areas due to unavailability of water resources.

Mr Manoj Shukla, Head, Flexible Pavement Department, CRRI, confirmed that waste plastic could only be used with hot mix. He added that cold mix is a climate resilient technology and could be used in any climatic condition. Cold mix technology gives better results in hot climate as the moisture is absent in aggregate. This absence of moisture results in better adhesion between aggregate and emulsion. He explained that in warm mix technology, some admixtures are added to the bitumen to make it workable at a lower temperature. He further described that in half-warm mix technology, the aggregate is heated up to 60 °C–70 °C and the performance of half warm mix was found to be better than cold mix in hot regions. He also specified that, life cycle assessment may not be possible all the time as rural roads are generally built in haste.

According to Mr Sanjiv Agnihotri, Executive Engineer, Himachal Pradesh PWD, cold mix has been a boon for Himachal Pradesh as use of hot mix in winters is difficult. However, in context of the performance of cold mix technology, he raised a problem regarding seal coat as sealing with cold mix is not proper. He also stated that surface dressing is not possible in rural roads in the state because of high rainfall and snow in winters, since these two factors lead to seepage of water which is harmful for the road surface.

Mr Th. Nandkishore, Chief Engineer, Manipur SRRDA, stated that in Manipur, 100 km of road has been constructed using cold mix technology. The performance of cold mix technology for premix was found to be satisfactory. However, they faced problems during seal coat, which was resolved through trial and error. He explained that stone grit and stone dust was being used for the construction works and the emulsion did not stick to the fine particles of stone dust. In order to resolve this issue, they made the particles coarser by segregating out fine dust through sieving. He also said that cold mix was more expensive and the consumption was also higher. Mr Rajan Singh, Chief Engineer, Manipur SRRDA, raised concerns regarding the small companies supplying cold mix and the quality of emulsion provided by them. He suggested that strict guidelines should be made by CRRI to check the quality of the emulsion. He also highlighted the necessity of capacity building of labour, since the performance of the cold mix technology depends of the quality of execution work done by them.

Mr S Vijay Kumar suggested that technical guidelines should be complemented with operational guidelines. He recommended that NRRDA pays close attention to the overall capacity of the system to transit towards operational guidelines. This could be achieved through gauging engineering capacity of implementing agency, strength of STAs, robustness of State Quality Monitors (SQMs) and National Quality Monitors (NQMs), and contractor strength. Where these capacities are strong, those states should be prioritized to transit towards cold mix. In addition, objective conditions like limited working season should be considered. He further added that use of new technology should not result in difficulties or incidences that would disincentivize others from using it.

Mr Hiremath responded that detailed specifications regarding cold mix technology are present in IRC Guidelines and the Standard Data Book of PMGSY. NRRDA recently released two quality assurance books wherein the guidelines are clearly stated.

Mr S Vijay Kumar highlighted the need for capacity building of STAs and SQMs. He added that the presence of IRC codes is no guarantee because SQM might show resistance to cold mix technology because of less/no experience in the cold mix technology. In his response, Mr Hiremath stated that NRRDA has initiated training of SQMs at the state level and so far, 15–16 states have already been covered, including NQMs. NRRDA is also focusing on training the SQMs and NQMs on the use of various technologies for conducting more informative and robust quality checks and has prepared fixed formats for the same. STAs are also being trained along with the SQMs.

Mr Hiranandy Sen, Additional Chief Engineer, Assam PWD, stated that in Assam, the use of cold mix started long back and so far, 2,400 km have been approved, 900 km completed, and the target for the current year stands at 433 km and cold mix is being used in all 23 districts. Mr S A Chaudhry, Additional Chief Engineer, Assam PWD, suggested that for life cycle assessment, additional study is required. Mr S Vijay Kumar mentioned that Assam has a dedicated training institution for engineers which may also be a factor for faster adoption of cold mix technology in the state. Mr SA Chaudhry, Deputy Director, PWRD, Assam raised his concern that that in the usage of cold mix, chances of soil pollution are higher as there may be accidental spilling of emulsion.

Mr R K Sharma, Assistant Engineer, Himachal Pradesh PWD, stated that the use of cold mix technology has just gained pace in Himachal Pradesh. Due to cold weather, the working season in the state is limited to about 3–4 months and it becomes difficult to work with hot mix technology in such a short period of time. However, it was seen that cold mix technology can be used in the rainy season and the results were found to be satisfactory. Mr S Vijay Kumar enquired if the cold mix technology has been used in extreme cold conditions to which Mr R K Sharma responded that cold mix technology has been used in Upper Kinnaur area and the seal coat gets deteriorated due the continuous seepage of water due to snow.

Mr T P Shangderpa, Chief Engineer, Sikkim SRRDA, stated that in Sikkim more than 100 km of road has been constructed using cold mix technology manufactured by BitChem. However, since the cold mix made by companies other than BitChem are cheaper, the contractors often do not want to use BitChem-manufactured cold mix. It was also seen that the performance of cold mix provided by other companies is similar to that of BitChem. Mr Shangderpa emphasized on the training of the PIUs regarding the methodology of laying process and the quality control of cold mix technology.

Mr Hiremath informed that NRRDA has a calendar of training events where proper training is imparted to the engineers regarding the use of cold mix technology. Mr Hiremath also emphasized on the need of testing the emulsion prior to using it for the purpose of construction. Mr S Vijay Kumar suggested that there is a need to set up training institutes at the state level rather that at the central level, to facilitate the training of various stakeholders in a more efficient way. Mr KM Verma, General Manager, MPRRDA, Madhya Pradesh, informed that such training activities are being carried in Madhya Pradesh at the regional level.

Mr Hozheto Shikhu, Executive Engineer, Nagaland PWD, stated that more than 500 km of rural roads, in Nagaland, have been constructed using cold mix technology. He said that hot mix technology is an energy- and labour-intensive technology. About 35 m^3/km of wood is burnt to construct the road. Many small brands/companies that manufacture cold mix emulsion and are comparatively cheaper than BitChem, are also emerging. However, the performance of these companies was not found to be satisfactory. Also, due to presence of large quantity of dust in aggregate, the deterioration of seal coat is a constant problem in Nagaland, to which Dr N K S Pundhir, Adviser, Hindustan Colas Ltd (Hincol), advised the use of liquid seal coat instead of sand seal coat.

Mr Ezikiel, Executive Engineer, Meghalaya PWD, stated that in Meghalaya, 430 km of rural roads has been constructed using cold mix technology. He inquired if there was any admixture that could be added to the cold mix emulsion to reduce its curing time. Ms Siksha Swaroopa Kar, Scientist, CSIR-CRRI, assured that there is no need to stop the traffic for the curing process since pressure of the tyre from the moving vehicle helps in the curing process. She also mentioned that the performance of cold mix technology is better in hot climate because of the absence of moisture in the aggregate and in addition, it was also seen that due to high temperatures, early strength in the pavement is gained faster as compared to other climatic conditions. She emphasized on the need of evaluation of cold mix technology in different traffic conditions. Due to climate conditions, the working season for construction of roads using hot mix technology is around 120 days only and due to unexpected delays, the work often does not get completed. However this problem has been solved by cold mix technology, which can be used in extreme cold conditions.

Mr Mukesh Gupta, ILO, stated that due to the overheating of the bitumen in hot mix technology, the inherent property of bitumen gets altered and hence, causes deterioration. Given the benefits, he recommended that the maintenance works should be carried out by cold mix technology only. He also encouraged the practice of surface dressing using cold mix emulsion.

Dr N K S Pundhir, Advisor, Hincol, reported that use of cold mix technology has been found satisfactory across various states in various climatic conditions. Hincol had done surface dressing on NH-2 using cold mix emulsion and found that the performance was better than pre mix carpet. He also pointed out that washing of aggregates was not required in cold mix technology.

Mr C M Attri, Director, BitChem, informed the stakeholders that roads using cold mix technology have been constructed using mechanized process (pavers) in Kangra, Hoshangabad, and Dharamshala. He mentioned that there is a resistance among the various government officials in adopting new technologies and so, it is important to extend certain incentives, in order to encourage the use of cold mix technology. It is also important to educate Gram Panchayats and the local people about the benefits of cold mix technology to facilitate easy adoption of the technology in the community.

Mr Mahesh Hiremath delivered the vote of thanks to all the participants and speakers.

9.7 Key Discussion Points: Study Workshop

9.7.1 Site selection for use of cold mix

Responding to the recommendation of the study regarding site/project specific use of cold mix technology, Mr A V Rajesh, Joint Director, NRRDA, suggested that TERI may develop suitable criteria. Over the course of discussion it was agreed that cold mix technology can be used at most of the different types of sites/projects and no specific criteria was required in this regard.

Suggestions/recommendations/response

Mr S Vijay Kumar suggested that instead of criteria based selection we should adopt an approach of prioritization of cold mix technology use in states based on criteria like

a. States where working period is less due to factors like rainfall and cold weather, cold mix can be prioritized to extend the working period of contractors and labour

b. Capacity of engineers to apply new technologies

c. Strength of State Technical Agencies to assess new technologies

d. Robustness of quality checks by SQMs and NQMs

e. Strength of contractors to use new technologies in their projects

f. Appropriate changes in the report recommendations with regard to this view were suggested to be made and the same have been incorporated in the final report.

9.7.2 Issues related to the quality provided by small brands/companies.

Representatives from ILO, Sikkim Rural Roads department and Nagaland Public Works Department highlighted the issue of poor performance of cold mix emulsion provided by small suppliers/ brands. They further explained that the emulsion provided by these suppliers are often cheaper than BitChem, hence the contractors prefer to use the emulsion provided by them.

Suggestions/recommendations/response

Mr Mahesh Hiremath suggested to the stakeholders to resolve this issue by undergoing tripartite agreements with the technology provides. He also suggested that the PIUs Should get the material tested by STAs before using it for construction purposes.

9.7.3 Capacity building for adoption of new technologies in states at various levels

Mr S Vijay Kumar emphasized on the need for capacity building of STAs and SQMs as the presence of IRC codes does not provide a guarantee regarding the use of cold mix technology because SQM might show resistance, due to less/no experience in the technology. Representatives from Manipur and Sikkim SRRDA, also stressed on the need of the training of PIUs and labour regarding the methodology of the laying process and quality control of cold mix technology.

Suggestions/recommendations/response

Mr Hiremath stated that NRRDA has initiated training of SQMs at the state level and so far, 15–16 states have already been covered, including NQMs. He also mentioned that STAs are also being trained along with the SQMs. Mr Hiremath also informed that NRRDA has a calendar of training events where proper training is imparted to the engineers regarding the use of cold mix technology.

Mr S Vijay Kumar suggested that there should be training institutes at the state level rather than at the central level; this will help in the training of various stakeholders in a more efficient way.

9.7.4 Community awareness/ involvement

Mr Anadi Charan Sahoo, Rural Works, Odisha mentioned that his department had faced resistance from local people at site since they do not accept cold mix technology. Mr S Vijay Kumar explained that rural roads are close to the community/people and they understand the process of road construction. The people are resistant to changes and prefer roads to be constructed by hot mix technology rather than cold mix technology.

Suggestions/recommendations/response

Mr Sahoo added that in order to resolve this issue, they had conducted various community participation programmes to mobilize society.

Mr S Vijay Kumar concurred and encouraged the use of local community labour for maintenance works. He suggested that local people should be convinced that maintenance of roads using local resources would be easier under the new technology. This kind of involvement would help gain local community's support and hence increase the acceptance of cold mix technology.

Participants from BitChem suggested that involvement of suppliers in mobilization and demonstration programmes would further boost confidence of the local population, as had been the experience wherever BitChem carried out such exercises.

9.7.5 Performance of seal coat using cold mix technology

During the discussion, issues were raised related to the performance of seal coat done using cold mix technology. Mr Th. Nandkishore, Manipur SRRDA, stated that the performance of cold mix technology for premix was found to be satisfactory but, they faced problems during seal coat. He further explained that stone grit and stone dust was being used for the construction works and the emulsion did not stick to the fine particles of stone dust. In order to resolve this issue, they made the particles coarser by segregating out fine dust through sieving. Similar problem was found in Nagaland also. Mr R K Sharma, PWD, Himachal Pradesh, mentioned that cold mix technology has been used in Upper Kinnaur area and the seal coat gets deteriorated due the continuous seepage of water due to snow.

Suggestions/recommendations/response

Dr N K S Pundhir, Adviser, Hindustan Colas (Hincol), suggested the use of liquid seal coat instead of sand seal coat wherever possible.

9.7.6 Curing time for cold mix technology

Mr Ezikiel, Meghalaya PWD, inquired if there was any admixture that could be added to the cold mix emulsion to reduce its curing time. He added that, as the curing time is higher for cold mix as compared to hot mix, they often need to stop the traffic for longer durations during curing period.

Suggestions/recommendations/response

Ms Siksha Swaroopa Kar, Scientist, CSIR-CRRI, assured that there is no need to stop the traffic for the curing process since pressure of the tyre from the moving vehicles helps in the curing process.

9.7.7 Use of cold mix for maintenance works and surface dressing

Mr Nabi Ahmad, Assistant Engineer, PWD, Bihar, enquired if surface dressing could be carried out properly using cold mix technology. Mr Sanjiv Agnihotri, PWD, Himachal Pradesh, mentioned that surface dressing using cold mix technology is not advisable in Himachal Pradesh because of high rainfall and snow in winters, since these two factors lead to seepage of water which is harmful for the road surface.

Suggestions/recommendations/response

Mr Mukesh Gupta, ILO, recommended that the maintenance works can be carried out using cold mix technology given its benefits of all-weather use. He also encouraged the practice of surface dressing using cold mix emulsion.

Dr. N K S Pundhir, Advisor, Hincol, reported that use of cold mix technology has been found satisfactory across various states in various climatic conditions. Hincol had done surface dressing on NH-2 using cold mix emulsion and found that the performance was better than pre mix carpet.

9.7.8 Soil Pollution due to cold mix

Mr S A Chaudhry, PWRD, Assam, raised his concern that in the usage of cold mix, chances of soil pollution are higher as there may be accidental spilling of emulsion.

Suggestions/recommendations/response

Ms Akshima Tejas Ghate, Senior fellow and Associate Director, TERI, responded that data related to on-site accidents was collected and record of such accidents however was not found for the sample projects. She also added the study of the effects of cold mix technology on the soil was not a part of study framework.

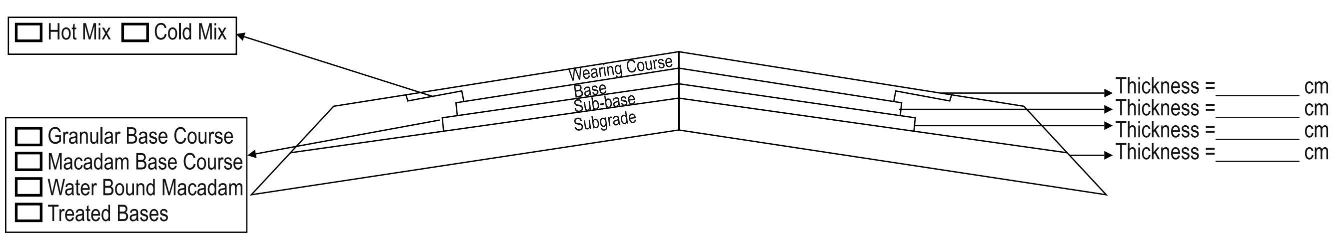
Questionnaire for collecting construction data for rural road projects

About the project

Name of the project:			Date:
State:			
Road start and end points:	From-	To-	Total distance between the two points (km): ______
Road length constructed as on date (km):	☐ Entire length constructed		☐ Partially constructed Length of road constructed till date _______km* *Please provide data for the constructed length of road, as on date
Construction duration:	Start date- End date/expected end date-		
Nature of construction: Green field/ up gradation (lower lanes to higher number of lanes) – Please specify details			
Pavement type:	☐ Flexible Pavement ☐ Rigid Pavement		
Design life of pavement (years):	__________________ Years		
Pavement Construction technology	☐ Hot Mix ☐ Cold Mix ☐ Other		
Cross-section details:	ROW: _______m, No. of lanes :_________, Carriage way width ________ m, ☐ Divided ☐ Undivided, Median width ________ m, shoulder______ m, Service road _________m Drainage: Type ________________ Diameter ____________; Other details______________________		
Other:	Is project DPR available: ☐ Yes ☐ No [If yes, please share DPR]		

Total Cost of the project	Rs ______________________ for ________ kms Specify what are the main items of this cost ☐ Construction materials ☐ Transport of materials ☐ Pavement Design and construction ☐ Labour cost ☐ Others (please specify)
Name of the contractor with contact details	

Cross sectional details of the road



EARTHWORK AND RETAINING WALLS												
USE OF CONSTRUCTION MATERIALS												
Construction materials used	Quantity used tonnes)	Cost of material		Source from where the construction material is brought		Typical mode used for transporting material from source					Cost of transportation (Rs)	
		Amount (Rs)	Unit (tonnes)	Place	Distance from site/ lead (in Kms)	Vehicle Type (Truck, Tempo, Etc)	No of trips*	Average loading on vehicle (tonnes)	Fuel Type (CNG/ Diesel)	Fuel efficiency (km/l)	Amount (Rs)	Unit
USE OF EQUIPMENTS AND LABOUR (Please write N.A if no equipments were used. If more than one equipment is used for the stage/activity/job please specify the details in Annexure-1)												
Stage	Equipment and machinery used				Total cost of Equipment and machinery used for carrying out the job#	Manpower used (No.)				Total cost of labour for carrying out the job# (Rs)	No of days in which activity was completed#	
	Name	Number	Fuel type	Fuel Efficiency (l/hr)		US**	SS**	S**	Total			
Preparation of surface												
Blasting (If any)												
Shoring and strutting												
Backfilling												
Clean-up												
Other steps (If any)												
All Jobs												
WASTAGE												
Type of wastage	Quantity of wastage (tonnes)	Was the waste sold? (Yes/No) If yes		Destination where the waste material was taken		Typical mode used for transportation of waste materials					Cost of transportation (Rs)	

		Amount (Rs)	Unit	Place	Distance from site/ lead	Vehicle Type (Truck, tempo, etc.)	No. of trips	Average loading on vehicle (Tonnes/ liters)	Fuel Type (CNG/ Diesel/ Petrol)	Fuel efficiency (Km/liters)	Amount (Rs)	Unit

In case stage wise data is not available, please provide the data for all jobs in the row "All Jobs"
* Please specify if these trips are one way or two ways
** US – unskilled. SS- Semi-skilled, S- Skilled

DRAINAGE WORKS

USE OF CONSTRUCTION MATERIALS

Construction materials used	Quantity used tonnes)	Cost of material		Source from where the construction material is brought		Typical mode used for transporting material from source					Cost of transportation (Rs)	
		Amount (Rs)	Unit (tonnes)	Place	Distance from site/ lead (in Kms)	Vehicle Type (Truck, Tempo, Etc)	No of trips*	Average loading on vehicle (tonnes)	Fuel Type (CNG/ Diesel)	Fuel efficiency (km/l)	Amount (Rs)	Unit

USE OF EQUIPMENTS AND LABOUR (Please write N.A if no equipments were used. If more than one equipment is used for the stage/activity/job please specify the details in Annexure-1)

Stage	Equipment and machinery used				Total cost of Equipment and machinery used for carrying out the job#	Manpower used (No.)				Total cost of labour for carrying out the job# (Rs)	No of days in which activity was completed#
	Name	Number	Fuel Type	Fuel Efficiency (l/hr)		US**	SS**	S**	Total		
Marking of Alignment											

Trench Digging												
Concrete binding												
Reinforcement positioning												
Side wall Panel construction												
Other steps (If any)												
All jobs												
WASTAGE												
Type of wastage	Quantity of wastage (tonnes)	Was the waste sold? (Yes\ No) If yes		Destination where the waste material was taken		Typical mode used for transportation of waste materials					Cost of transportation (Rs)	
		Amount (Rs)	Unit	Place	Distance from site/ lead	Vehicle Type (Truck, tempo ,etc.)	No. of trips	Average loading on vehicle (tonnes)	Fuel Type (CNG/ Diesel)	Fuel efficiency (km/l)	Amount (Rs)	Unit

[#] In case stage wise data is not available, please provide the data for all jobs in the row "All Jobs"

* Please specify if these trips are one way or two ways

** US – unskilled. SS- Semi-skilled, S- Skilled

PAVEMENT CONSTRUCTION												
USE OF CONSTRUCTION MATERIALS												
Construction materials used	Quantity used tonnes)	Cost of material		Source from where the construction material is brought		Typical mode used for transporting material from source					Cost of transportation (Rs)	
		Amount (Rs)	Unit (tonnes)	Place	Distance from site/ lead (in Kms)	Vehicle Type (Truck, Tempo, Etc)	No of trips*	Average loading on vehicle (tonnes)	Fuel Type (CNG/ Diesel)	Fuel efficiency (km/l)	Amount (Rs)	Unit

USE OF EQUIPMENTS AND LABOUR (Please write N.A if no equipments were used. If more than one equipment is used for the stage/activity/job please specify the details in Annexure-1)

Stage	Equipment and machinery used				Total cost of Equipment and machinery used for carrying out the job#	Manpower used (No.)				Total cost of labour for carrying out the job# (Rs)	No of days in which activity was completed#
	Name	Number	Fuel type	Fuel Efficiency (l/hr)		US**	SS**	S**	Total		
Preparation of subgrade											
Preparation of sub-base											
Preparation of base											
Preparation of Pavement Surface											
Other Steps (If any)											
All Jobs											

WASTAGE

Type of wastage	Quantity of wastage (tonnes)	Was the waste sold? (Yes/No) If yes		Destination where the waste material was taken		Typical mode used for transportation of waste materials					Cost of transportation (Rs)	
		Amount (Rs)	Unit	Place	Distance from site/ lead	Vehicle Type (Truck, tempo, etc.)	No. of trips	Average loading on vehicle (Tonnes/ liters)	Fuel Type (CNG/ Diesel/ Petrol)	Fuel efficiency (Km/liters)	Amount (Rs)	Unit

In case stage wise data is not available, please provide the data for all jobs in the row "All Jobs"
* Please specify if these trips are one way or two ways
** US – unskilled. SS- Semi-skilled, S- Skilled

PAVEMENT SURFACE

USE OF CONSTRUCTION MATERIALS												
Construction materials used	Quantity used tonnes)	Cost of material		Source from where the construction material is brought		Typical mode used for transporting material from source					Cost of transportation (Rs)	
		Amount (Rs)	Unit (tonnes)	Place	Distance from site/ lead (in Kms)	Vehicle Type (Truck, Tempo, Etc)	No of trips*	Average loading on vehicle (tonnes)	Fuel Type (CNG/ Diesel)	Fuel efficiency (km/l)	Amount (Rs)	Unit

USE OF EQUIPMENTS AND LABOUR (Please write N.A if no equipments were used. If more than one equipment is used for the stage/activity/job please specify the details in Annexure-1)											
Stage	Equipment and machinery used				Total cost of Equipment and machinery used for carrying out the job#	Manpower used (No.)				Total cost of labour for carrying out the job# (Rs)	No of days in which activity was completed#
	Name	Number	Fuel Type	Fuel Efficiency (l/hr)		US**	SS**	S**	Total		
Preparation of surface											
Tack Coat Application											
Pre- Mix carpet Preparation											
Spreading and rolling of pre-mix carpet											
Seal coat application											

Other Steps (If any)											
All Jobs											

WASTAGE											
Type of wastage	Quantity of wastage (tonnes)	Was the waste sold? (Yes\ No) If yes		Destination where the waste material was taken		Typical mode used for transportation of waste materials					Cost of transportation (Rs)	
		Amount (Rs)	Unit	Place	Distance from site/ lead	Vehicle Type (Truck, tempo ,etc.)	No. of trips	Average loading on vehicle (tonnes)	Fuel Type (CNG/ Diesel)	Fuel efficiency (km/l)	Amount (Rs)	Unit

In case stage wise data is not available, please provide the data for all jobs in the row "All Jobs"
* Please specify if these trips are one way or two ways
** US – unskilled. SS- Semi-skilled, S- Skilled

ROAD MARKINGS AND TRAFFIC SIGNS

USE OF CONSTRUCTION MATERIALS											
Construction materials used	Quantity used tonnes)	Cost of material		Source from where the construction material is brought		Typical mode used for transporting material from source					Cost of transportation (Rs)	
		Amount (Rs)	Unit (tonnes)	Place	Distance from site/ lead (in Kms)	Vehicle Type (Truck, Tempo, Etc)	No of trips*	Average loading on vehicle (tonnes)	Fuel Type (CNG/ Diesel)	Fuel efficiency (km/l)	Amount (Rs)	Unit

USE OF EQUIPMENTS AND LABOUR (Please write N.A if no equipments were used. If more than one equipment is used for the stage/activity/job please specify the details in Annexure-1)											
Stage	Equipment and machinery used				Total cost of Equipment and machinery used for carrying out the job#	Manpower used (No.)				Total cost of labour for carrying out the job# (Rs)	No of days in which activity was completed#
	Name	Number	Fuel type	Fuel Efficiency (l/hr)		US**	SS**	S**	Total		

Preparation/ Cleaning of surface												
Marking centre line												
Application of thermoplastic paint												
Preparation of base for signal and sign post												
Placing sign and signal posts												
Other Steps (If any)												
All Jobs												
WASTAGE												
Type of wastage	Quantity of wastage (tonnes)	Was the waste sold? (Yes/No) If yes		Destination where the waste material was taken		Typical mode used for transportation of waste materials					Cost of transportation (Rs)	
		Amount (Rs)	Unit	Place	Distance from site/ lead	Vehicle Type (Truck, tempo, etc.)	No. of trips	Average loading on vehicle (Tonnes/ liters)	Fuel Type (CNG/ Diesel/ Petrol)	Fuel efficiency (Km/liters)	Amount (Rs)	Unit

In case stage wise data is not available, please provide the data for all jobs in the row "All Jobs"

* Please specify if these trips are one way or two ways

** US – unskilled. SS- Semi-skilled, S- Skilled

Information on on-site electricity and fuel consumption (for the road length constructed)

Electricity consumption	
1. What was the on-site electricity usage during project construction phase for on-site lighting, field offices, running machinery/equipment, labour camps, etc.?	Total electricity purchased from electricity distribution company/ state electricity board (as on date): ________ (Unit _____)
2. Was there on-site generation of electricity by using electric generators? If yes, then please give the details of diesel quantity/other fuels used for electricity generation.	No. of generators used: ________ Fuel type used in generators: ____ Total quantity of each fuel type used in generators (as on date): Fuel_______ Quantity_______ Unit_____ Fuel_______ Quantity_______ Unit_____ Fuel_______ Quantity_______ Unit_____ Fuel_______ Quantity_______ Unit_____ What is the average daily use of generators?: ______hours

Consumption of fossil fuels and biomass			
What was the quantity of fuels consumed on-site for running machinery and vehicles (as on date)? (excluding use of fuel in generators)	Fuel	Quantity	Unit
	Diesel		Liters
	Petrol		Liters
	CNG		Tonnes
	Furnace oil		Liters
	LDO		Liters
	Kerosene		Liters
	LPG		Liters
	Natural gas		Tonnes
	Biomass		Tonnes
	Timber		Tonnes

USE OF EQUIPMENTS AND LABOUR (Annexure -1)

Stage/Activity/ Job	Equipment and machinery used				Total cost of Equipment and machinery used for carrying out the job	Manpower used (No.)				Total cost of labour for carrying out the job (Rs)	No of days in which activity was completed
	Name	Number	Fuel type	Fuel Efficiency (Km/L)		US**	SS**	S**	Total		

Additional Data

INFORMATION ON HABITATION\POPULATION	
No. of habitations in the vicinity of the stretch	
Population of the habitations	

INFORMATION ON STAFF MEMBERS AND LABOURS WORKING ON THE SITE FOR THE TOTAL CONSTRUCTION PERIOD	
Staff members working on site	
Skilled labour on site	
Unskilled labour on site	
Semi- Skilled labour on site	

INFORMATION ON ACCIDENTS			
Type of Accident	Total	Fatal Injuries	Deaths
No. of accidents that occurred during construction of road			
No. of accidents on account of hot/cold mix technology			

INFORMATION ON DELAYS	
No. of delays in construction	
Causes of delays	

Questionnaire for collecting periodic maintenance data for rural road projects

About the Rural Roads

Name of the project			Date:
Road section maintained: (Road start and end points)	From-	To-	Total distance between the two points (km):
State:			
Pavement type:_______________	☐ Flexible Pavement (Bituminous surface) ☐ Rigid pavement (Concrete surface)		
Pavement construction technology:	☐ Hot mix ☐ Cold mix ☐ Other _______________________		
Cross-section details	ROW: _______m, No. of lanes :__________, Carriage way width _________ m, ☐ Divided ☐ Undivided, Median width _________ m, Shoulder_______ m, Service road __________m Drainage: Type _______________ Diameter _____________; Other details___________________		
When was the road constructed? (Completion date of road construction)	_____Month _____ Year		
What is the expected life of the road pavement?	_______________________ Years		
Total Cost of the project	• Initial cost of construction of road Rs ____________ for _________ kms Details of periodic maintenance • Periodic maintenance carried out _________ times in _________ years • Periodic maintenance\ Renewal* conducted in the year/s__________ Cost of Periodic maintenance\ Renewal*:- • Year _______ and cost Rs ____________ for _________ kms • Year _______ and cost Rs ____________ for _________ kms • Year _______ and cost Rs ____________ for _________ kms		
What are the key periodic maintenance activities? [Eg. drainage repair, retaining wall repair, major patchwork, renewal of wearing course]			

*Renewal of wearing course\surface

PERIODIC MAINTENANCE (PLEASE SHARE DETAILS FOR EACH YEAR OF MAINTENANCE WORK)	
Year for which data has been provided	
Length of the road for which maintenance work was carried out (kms)	
Duration of periodic maintenance works	____________ (Months\Weeks)
Total cost of the periodic maintenance work	

USE OF CONSTRUCTION MATERIALS

Construction materials used	Quantity used (tonnes)	Cost of material		Source from where the construction material is brought		Typical mode used for transporting material from source					Cost of transportation (Rs)	
		Amount (Rs)	Unit (tonnes)	Place	Distance from site/ lead (in Kms)	Vehicle Type (Truck, Tempo etc.)	No of trips*	Average loading on vehicle (tonnes)	Fuel Type (CNG/ Diesel)	Fuel efficiency (kms/l)	Amount (Rs)	Unit

USE OF EQUIPMENTS AND LABOUR (Please write N.A if no equipments were used)

Equipment and machinery used				Total cost of Equipment and machinery used for carrying out the job#	Manpower used at site (No.)				Total cost of labour for carrying out the job# (Rs)	No of days in which activity was completed#
Name	Number	Fuel Type	Fuel Efficiency (l/hr)		US**	SS**	S**	Total		
All Jobs										

WASTAGE

Type of wastage	Quantity of wastage (tonnes)	Was the waste sold? If yes		Destination where the waste material was taken		Typical mode used for transportation of waste materials					Cost of Transportation	
		Amount (Rs)	Unit	Place	Distance from site/ lead	Vehicle Type (Truck, tempo ,etc)	No. of trips	Average loading on vehicle (Tonnes)	Fuel Type (CNG/Diesel/ Petrol)	Fuel efficiency (kms/l)	Amount (Rs)	Unit

#In case stage wise data is not available, please provide the data for all jobs in the row "All Jobs"
* Please specify if these trips are one way or two ways
** US – unskilled. SS- Semi-skilled, S- Skilled

Information on on-site electricity and fuel consumption (for the Periodic Maintenance)

Electricity consumption	
1. What was the on-site electricity usage during project maintenance phase for on-site lighting, field offices, running machinery/equipment, labour camps, etc.?	Total electricity purchased from electricity distribution company/ state electricity board (as on date): ________ (Unit _____) Average tariff at which electricity was made available: Rs____________per (Unit________)
2. Was there on-site generation of electricity by using electric generators? If yes, then please give the details of diesel quantity/other fuels used for electricity generation.	No. of generators used: ________ Fuel type used in generators: ____ Total quantity of each fuel type used in generators (as on date): Fuel_______ Quantity_______ Unit_____ Fuel_______ Quantity_______ Unit_____ Fuel_______ Quantity_______ Unit_____ Fuel_______ Quantity_______ Unit_____ What is the average daily use of generators?: ______hours

Consumption of fossil fuels and biomass			
What was the quantity of fuels consumed on-site for running machinery and vehicles (as on date)? (excluding use of fuel in generators)	Fuel	Quantity	Unit
	Diesel		Liters
	Petrol		Liters
	CNG		Tonnes
	Furnace oil		Liters
	LDO		Liters
	Kerosene		Liters
	LPG		Liters
	Natural gas		Tonnes
	Biomass		Tonnes
	Timber		Tonnes

Questionnaire for collecting routine maintenance data for rural road projects

About the Rural Roads

Name of the project			Date:
Road section maintained: (Road start and end points)	From-	To-	Total distance between the two points (km): ____________________
State:			
Pavement type:__________	☐ Flexible Pavement (Bituminous surface) ☐ Rigid pavement (Concrete surface)		
Pavement construction technology:	☐ Hot mix ☐ Cold mix ☐ Other ______________		
Cross-section details	ROW: _______m, No. of lanes :_________, Carriage way width ________ m, ☐ Divided ☐ Undivided, Median width ________ m, Shoulder______ m, Service road _________m Drainage: Type ______________ Diameter ___________; Other details____________________		
When was the road constructed? (Completion date of road construction)	_____Month _____ Year		
What is the expected life of the road pavement?	____________________ Years		

Total Cost of the project	Initial cost of construction of road Rs ___________ for ________ kms Routine maintenance* cost 1.Year _______ and cost Rs ___________ for ________ kms 2.Year _______ and cost Rs ___________ for ________ kms 3.Year _______ and cost Rs ___________ for ________ kms 4.Year _______ and cost Rs ___________ for ________ kms 5.Year _______ and cost Rs ___________ for ________ kms 6.Year _______ and cost Rs ___________ for ________ kms 7.Year _______ and cost Rs ___________ for ________ kms 8.Year _______ and cost Rs ___________ for ________ kms 9.Year _______ and cost Rs ___________ for ________ kms 10.Year _______ and cost Rs ___________ for ________ kms
What are the key routine maintenance activities? [e.g. patch repairs, crack sealing, repairing shoulders, painting (signs, km stones, road markings, etc.), vegetation removal]	

*Activities like patch repairs, crack sealing, repairing shoulders, painting (signs, km stones, road markings, etc.), and vegetation removal

ROUTINE MAINTENANCE (PLEASE SHARE DETAILS FOR ONE YEAR MAINTENANCE WORK)	
Year for which data has been provided	
Length of the road for which routine maintenance work was carried out (kms)	
Duration of routine maintenance works	____________________ (Months\Weeks)
Total cost of the Routine maintenance work	

USE OF CONSTRUCTION MATERIALS

Construction materials used	Quantity used (tonnes)	Cost of material		Source from where the construction material is brought		Typical mode used for transporting material from source					Cost of transportation (Rs)	
		Amount (Rs)	Unit (tonnes)	Place	Distance from site/ lead (in kms)	Vehicle Type (Truck, tempo etc.)	No of trips*	Average loading on vehicle (tonnes)	Fuel Type (CNG/ Diesel)	Fuel efficiency (kms/l)	Amount (Rs)	Unit

WASTAGE

Type of wastage	Quantity of wastage (tonnes)	Was the waste sold? (Yes/No) If yes		Destination where the waste material was taken		Typical mode used for transportation of waste materials					Cost of Transportation	
		Amount (Rs)	Unit	Place	Distance from site/ lead	Vehicle Type (Truck, tempo ,etc	No. of trips	Average loading on vehicle (Tonnes)	Fuel Type (CNG/Diesel/ Petrol)	Fuel efficiency (kms/l)	Amount (Rs)	Unit

Information on on-site electricity and fuel consumption (for the Routine Maintenance)

Consumption of fossil fuels and biomass			
What was the quantity of fuels consumed on-site for running machinery and vehicles (as on date)?	Fuel	Quantity	Unit
	Electricity		KW-hr
	Diesel		Liters
	Petrol		Liters
	CNG		Tonnes
	Furnace oil		Liters
	LDO		Liters
	Kerosene		Liters
	LPG		Liters
	Natural gas		Tonnes
	Biomass		Tonnes
	Timber		Tonnes

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