LIFE CYCLE ANALYSIS OF TRANSPORT MODES

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ABSTRACT

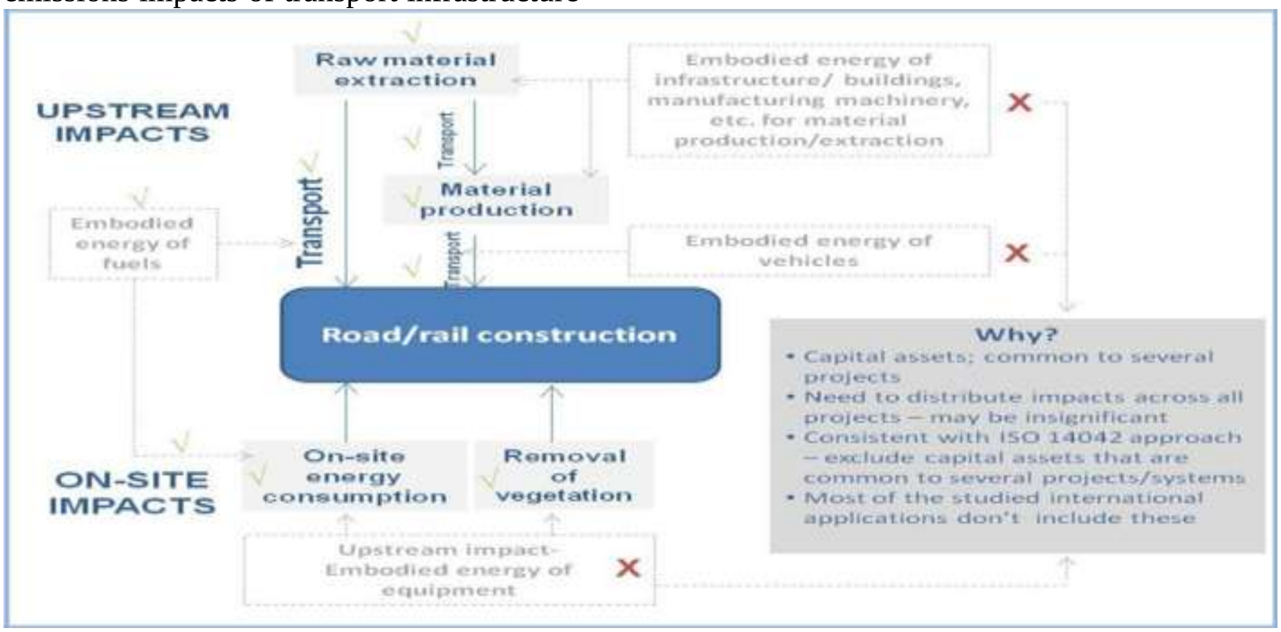
Environmental impact assessment exercises carried out to support decision-making in transport sector do not consider the full life cycle energy and CO2impacts of transport modes and focus on the tail pipe impacts only. It is, however, necessary that a holistic approach is adopted while analyzing the impacts of the sector. Different transport modes involve varying degrees of construction and maintenance activities; while some modes may be highly material and energy intensive, the others may be comparably low intensive. Material and energy consumption at various stages of a transport project i.e. construction, operations and maintenance needs to be examined in order to fully understand its impacts on environment. Life cycle analyses (LCA) are typically used to assess such holistic/full-life impacts of various products, systems, projects, etc. ISO 14042 defines LCA as a systematic way of evaluating the environmental impacts of products or activities by following a 'cradle to grave' approach. It involves identification and quantification of material and energy consumption and emissions which affect the environment at all stages of the entire product life cycle.

LCA is considered to be a robust decision support tool due to the comparative character of the analysis performed in the LCA framework. It helps identify life stages of a product/system having maximum impact hence enabling identification of appropriate mitigation strategies. Application of LCA to transport sector becomes important as transport impacts are not limited to tail-pipe only. Full life cycle impacts of transport need to be accounted and recognized while taking policy decisions related to 'greening' of the sector. The National Transport Development Policy Committee (NTDPC)established by the Government of India aims to understand the life cycle impacts in terms of energy consumption and CO2emissions associated with various life stages of different transport modes in order to make informed choices for climate-friendly and energy efficient modes for the country and for suggesting intra-mode improvements to reduce these impacts. In absence of any comprehensive LCA study for transport sector in India, NTDPC has commissioned a study to TERI focusing on establishing a robust India-specific methodology to estimate the life cycle impacts of transport modes in terms of energy consumption and CO2emissions and measuring these impacts for typical transport projects. The selected modes for this study include three urban transportation systems i.e. urban road, Bus Rapid Transit System (BRTS), and Metro Rail Transit System (MRTS) and two long-distance modes i.e. National Highway (NH), and long-distance passenger railway. As stated earlier, all stages in the life cycle of a transport mode like construction of fixed infrastructure, manufacture of rolling stock, movement of rolling stock for transportation of people/goods, maintenance of rolling stock, maintenance of fixed infrastructure, etc. require material and energy consumption and lead to CO2emissions. The life cycle analysis proposed in this study takes into account all these life stages of transport modes. However, certain stages/activities have been left out/not included in the LCA system boundary in order to ensure that the proposed LCA methodology is doable. The system boundary defined in this study is in line with the several international applications of LCA in transport sector.

INTRODUCTION

India is witnessing massive construction activities in infrastructure sectors. Transport sector in particular has seen significant construction of highways, roads, ports, railways, and airports over the last decade. Undoubtedly, creation of transportation infrastructure has had an important role in the fast pace of economic growth being observed in the country but not without its impact on environment. Although large scale transport projects are subjected to techno-economic feasibility and environmental impact analysis, energy and climate change considerations do not particularly form the basis of decisions regarding which transport projects/modes to be promoted. In today‟s times, when the sensitivity towards energy security and climate change concerns has grown, it is important that the decisions related to transport sector growth take due consideration of these for all stages of transport infrastructure creation. Construction and maintenance stages of transport projects are usually ignored while understanding the energy impacts; focus typically being on the tail-pipe impact of transport operations.

As stated in the Volume I, this study is aiming to estimate the energy and CO2 emissions impacts of transport infrastructure for all its life stages: construction, operations and maintenance so that these results can be used in decisions related to mode choice in addition to the economic and environmental criteria existing today. The study has selected five types of transport infrastructure – National Highways (NH), long-distance rail, urban roads, Bus Rapid Transit System (BRTS) and metro rail system. This section is aiming to highlight the construction stage impacts of all these five modes in terms of material and energy consumption. Figure 1.1 describes the scope of impact analysis for construction stage of transport infrastructure projects considered in this study.



Embodied energy of materials is defined as the sum total of all energy sequestered in construction materials during all processes of production, on-site construction and final demolition and disposal.2

Embodied energy of construction materials can be divided into following stages:

- Energy used during extraction, processing and manufacturing of materials;
- Energy used in transportation of finished materials from manufacturing/ prefabrication plant to site;

Once construction materials reach the site, energy consumption occurs in:

- Installation of materials/construction on site;
- Maintenance over the life cycle of the material; and
- Disposal.

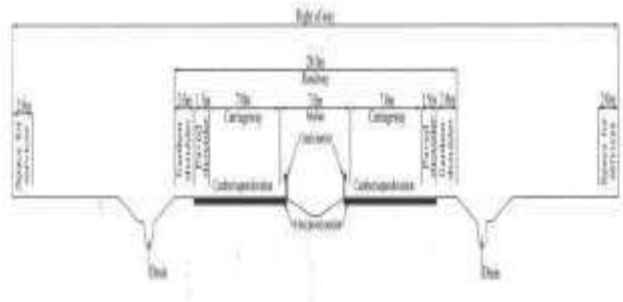
It is expected that embodied energy of construction materials forms a significant proportion of the overall energy consumed during the lifecycle of a given mode of transport. Therefore, it becomes critical to understand the embodied energy values of the key construction materials used in the transportation sector.

Road construction (National Highways and urban roads)

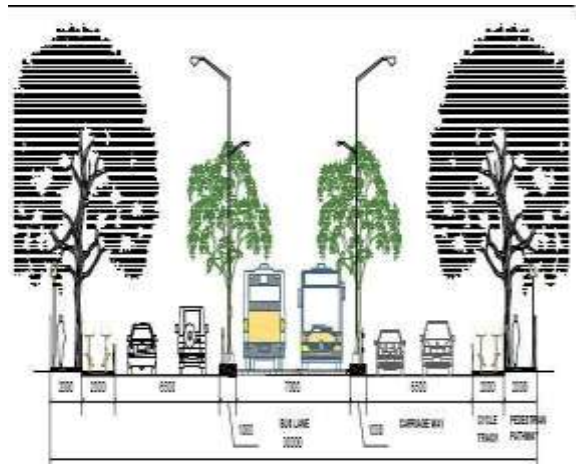
Government of India has been promoting the growth of roads sector during the past decade and has launched several programmes to channelize the same. The scale of road construction activities being undertaken in the country can be gauged from the fact that the road sector expenditures have gone up from 3% of the total Plan expenditure in the Ninth Five Year Plan (1997-2002), to almost 12% today6. The central sector outlay for road transport sector for the Eleventh Five Year Plan at current prices was Rs. 11.31 billion. Considering that typically 95% of the road sector budget is used for civil works, about Rs. 10.75 billion is expected as being utilized in construction of roads in the current Plan period. A large portion of this investment is being utilized for the construction of National Highways.

The current phases of the National Highway Development Programme (NHDP) of the government target improving about 48,000 km of arterial routes of NH Network to international standards. This has translated into massive construction activities being undertaken throughout the country. Table 1.2 gives the status of road construction activities undertaken by the National Highways Authority of India (NHAI) as on 29 February, 2012; NHAI had completed four-laning of more than 17,000 kms of highways and aims to undertake additional construction of about 19,900 kms under its flagship initiatives.

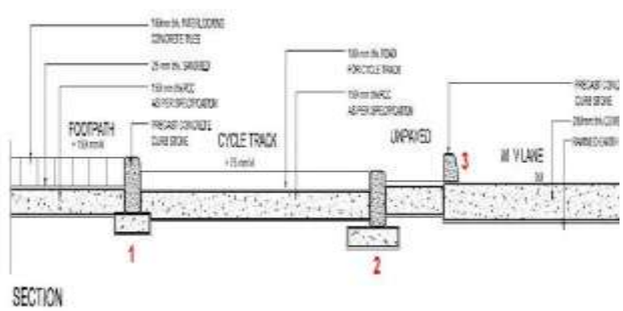
Typical cross section of a 4-lane divided highway



Typical cross section of BRTS for ROW of 30 metres



Detailed BRTS section showing segregated footpath, cycle track and motor vehicle lane



LITERATURE REVIEW

As stated in the previous section, India is in the course of developing huge amount of transport infrastructure. Large scale investments are being made to create/improve transport infrastructure in the country. This translates into huge maintenance requirements of the assets that are being created; the amount of focus given on maintaining these assets will have a significant role in deciding the longevity of these investments/life of the assets being created.

Conventionally, maintenance has been a neglected subject; especially in the roads sector. According to the Asian Development Bank"s recent paper on transport sector,,,for every $1 of essential maintenance that is postponed the operating costs of vehicles increase by more than $3." Due to shortcomings in maintenance of road infrastructure in India44, there is more emphasis on new road construction over road maintenance, as a result of which maintenance backlogs get built up, which also forces early re-construction. Maintenance hence is a key component in the life cycle of transport infrastructures and needs due attention.

Similar to construction, maintenance activities also have a huge impact on the material and energy consumption. Since the focus of this study is to understand these impacts for full life cycle of transport infrastructures, this section aims to understand the typical maintenance practices followed for the five selected modes of transport in order to understand material and energy inputs for the same.

Road maintenance activities can be categorized into following:

- 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 and are funded from the recurrent budget; these can be grouped into cyclic and reactive works types. Cyclic works are those undertaken where the maintenance standard indicates the frequency at which activities should be undertaken. Examples are verge cutting and culvert cleaning, works after monsoons, all of which are dependent on environmental effects rather than on traffic levels. Reactive works are those where intervention levels, defined in the maintenance standard, are used to determine when maintenance is needed. An example is patching, which is carried out in response to the appearance of cracks or pot-holes.
- Periodic maintenance – Periodic maintenance activities are undertaken at intervals of several years 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 (carried out regularly but at long intervals) and its periodicity depends on factors like pavement design, traffic loads, environmental impacts, etc. Periodic maintenance activities usually exclude works that change the geometry of a road by widening or realignment. Works can be grouped into the works types of preventive, resurfacing, overlay and pavement reconstruction. Examples of periodic works include resealing and overlay works/provision of renewal coat to the wearing surface.

- Emergency maintenance or Special works – These works cover those situations which call for a rapid response to restore the road pavement in order to ensure the safety of the road users. These works cannot be planned/estimated in advance. The works could involve pavement restoration after heavy rains/flood; cyclone, landslides, or winter maintenance works of snow removal or salting.
- Rehabilitation works – These works cover those activities that restore or increase the structural strength of the road pavement to extend its life and safety for the road users. These works do not generally require any removal of the existing pavement. Example of rehabilitation works could be increasing the structural strength of the pavement by adding material, such as crushed stone on top of the existing pavement and then laying a base course and wearing course on top of the crushed stone.
- Reconstruction and upgrading – These works include those activities which restore, and generally improve the structural and other aspects of the existing road. E.g.: widening of pavement around a curve, realignment of a small length of a road, sealing gravel shoulders, replacement of an existing structure, enlarging an existing culvert, improving an intersection layout and the bituminous surfacing of a short length of gravel road.

RESULTS & DISCUSSION

Four laning of Rohtak-Bawal (Haryana) section of NH-71 was studied. The details about the project are given in table 3.1. Rewari Project Implementation Unit (PIU) of National Highways Authority of India (NHAI) facilitated the data collection from Kurukshetra Expressway Pvt. Ltd. (KEPL). KEPL is executing the project on Design, Build, Finance, Operate and Transfer (DBFOT) basis.

Table: Details of the NH construction project studied

Project:	Four Laning of Rohtak-Bawal section of NH-71 under NHDP III on DBFOT basis		
State:	Haryana		
Road start and end points:	From- Chainage 363.30	To- Chainage 445.85	Total distance between the two points: 82.55 km (4 lanes)
Road length constructed as on date when construction data was collected:	10.37 km		
Construction duration:	Start date- 10th May, 2011 Expected end date- November, 2013		
Design life of pavement (years):	10 Years		
Cross-section details	60 m ROW, 4 lane road, 8.75 m one-side carriage way, 4.5 m median, 1.5 meter shoulder, 8.0 m width service road one-side (In urban stretches and by-passes i.e. 16 km length - service		

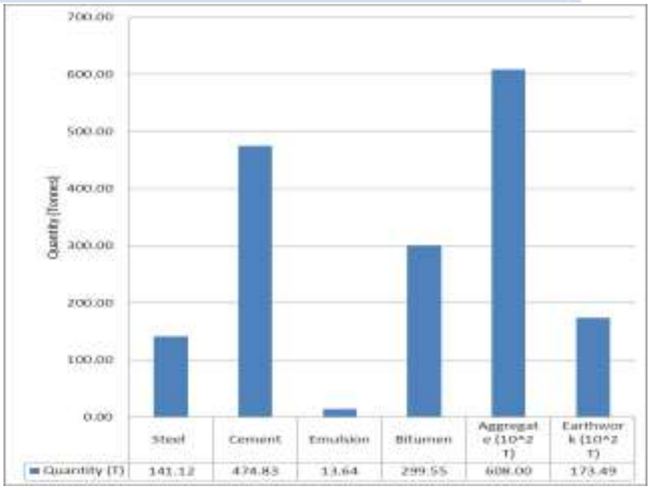
Consumption of materials during construction

Key materials consumed for NH construction include:

- Aggregate
- Bitumen
- Bitumen emulsion
- Cement
- Earth (cut and fill)

Per kilometre consumption of key materials in construction of NH is given in figure 4.1.

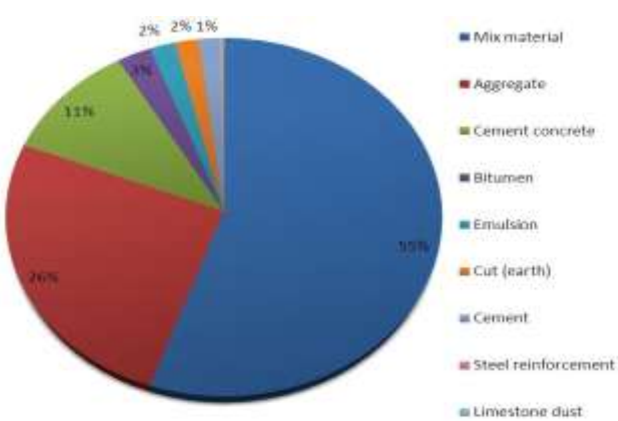
Figure Consumption of key materials- 1 km NH construction



Construction of 1 km NH involves significant consumption of aggregates (coarse/fine); about 60 thousand tonnes of aggregates are consumed per km. Construction also involves substantial amount of earthwork in the form of cut and fills on the site. In the Rohtak-Bawal section studied, earthwork to the tune of about 17 thousand tonnes was carried out. About 300 tonnes of bitumen was used per km. The road section studied also involved use of cement (about 475 tonnes), and steel (about 140 tonnes), primarily for construction of culverts, small bridges, kerb channels, etc.

Photographs of construction of Rohtak-Bawal NH

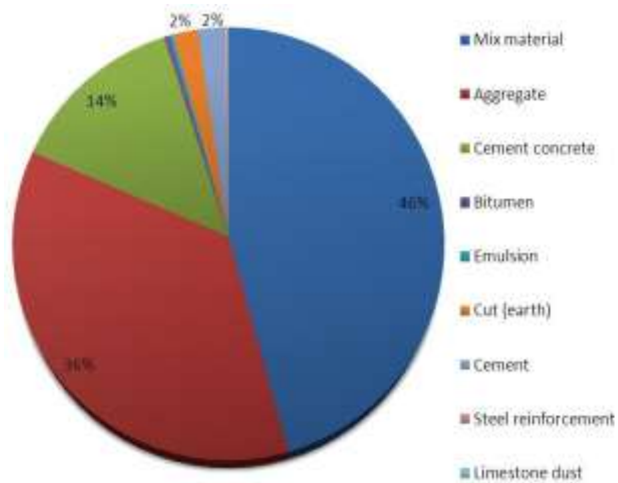
Fig: Contribution of different materials to embodied energy of materials used per km



city road construction

Source: Analysis by TERI

Figure Contribution of different materials to embodied CO_2 of materials used per km city road construction



Source: Analysis by TERI

CONCLUSION

The study has sought to establish a comprehensive and robust methodology to estimate the life cycle energy and CO2 emissions impacts of transport modes. The methodology can help take into account the energy efficiency and CO2 impacts before arriving at investment decisions related to choice of transport modes. This becomes particularly important in the context of ongoing concerns regarding energy security and climate change impacts of transport sector.

The application of the LCA methodology in this study indicates that LCA is doable for transport projects. This is indeed the biggest contribution of the study. The study has contributed in shifting focus to life stages of transport projects (i.e. construction, maintenance, manufacture of rolling stock, etc.) that are usually ignored while assessing environmental impacts. The study is useful in two ways- it can help in choice of modes and in improvement within the modes.

The life cycle analysis carried out for typical transport projects using the proposed LCA methodology indicates that there are significant energy and CO2 related impacts of transport systems throughout their life. Currently, the decision-making processes consider the energy and CO2 impacts due to movement of rolling stock only, which gives an incomplete assessment of impacts. In addition to impacts due to rolling stock movement, there are significant energy and CO2 impacts due to construction and maintenance of transport infrastructure. Construction and maintenance of transport infrastructure involves consumption of materials and fuels, some of which are highly energy and carbon intensive. LCA results indicate significant contribution of such materials and fuels to life cycle energy and CO2 impacts of transport modes. Using alternative materials and fuels that are less energy and carbon intensive and are locally available can help reduce these impacts. Research studies on alternative materials and fuels should be conducted in order to identify energy efficient and low-carbon substitutes to conventional materials and fuels.

The results of this study show that an understanding of the full-life cycle energy and CO2 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 choice of mode or promoting modal shift towards more 'green' modes, life cycle analysis can also help in intruded greening, as it helps understand the share of various components that contribute to energy consumption and CO2 emissions, hence helping in identifying the appropriate mitigation measures.

Also, understanding the extent of impacts and reasons for the same will help identify the mitigation measures to reduce the impacts. Some possible areas where energy reduction can be achieved during the life of a transportation system are:

- Reducing energy and CO2 intensity of conventional materials used,
- Using alternative materials that are comparatively less energy and CO2 intensive,
- Using locally available materials,
- Using energy efficient processes and machinery during construction and maintenance, Life cycle analysis of transport modes
- Optimizing resource utilization during construction and maintenance, especially for transportation of materials (using locally available materials, reducing idling, using rail for bulk transport of materials, etc.),
- Promoting inter-modal shift (towards more energy efficient modes),
- Improving efficiency of rolling stock, and
- Reducing energy and material intensity during manufacturing and maintenance of rolling stock.

The study findings also indicate that if life of projects is enhanced, then the energy and CO2 impacts due to re-construction can be reduced/deferred, especially in the case of road-based projects that tend to have shorter life. Life of the projects can be enhanced by continued maintenance. Maintenance of constructed assets should hence be given due importance; it will help reduce both monetary and environmental costs on a life cycle basis.

Traditional environmental impact asessment exercises carried out to support decision-making in transport sector do not consider the full life cycle energy and CO2 impacts of transport modes. It is important that decisions related to choice of transport modes consider the life cycle impacts in terms of energy and CO2 emissions in addition to other financial, technical, and environmental criteria used today.

In addition to financial and technical feasibility and environmental impact assessment exercises carried out at project selection/development stage, LCA estimating energy and CO2 impacts should also be carried out. As stated earlier, this study has sought to establish a robust methodology to estimate the life cycle impacts. Further work is necessary to fine-tune the methodology and adapt it for use on a continuous basis for taking informed investment decisions. The successful use of the methodology will depend on the data available and data availability is a challenge in India. Database should be constructed to support the LCA.

Hence, to be able to use LCA in transport sector decision making, research and supporting Database creation should be encouraged and supported by the government.

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