A life cycle analysis of urban public transport systems in Indian cities

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First author: Ms Akshima T Ghate
Second author: Mr Sharif Qamar

Why LCA in transport sector?

- Transport impacts not limited to tail-pipe emissions only
- Significant environmental impacts not just during operations but also during construction and maintenance
- Full life cycle impacts of transport need to be accounted while taking policy decisions in establishing facilities
- LCA helps in holistic environmental impact analysis of transport systems

Adapting the framework for LCA

Life Cycle Assessment (LCA)

LCA is 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 of life cycle (ISO 14042)

Material consumption

Energy consumption

INPUT

All life stages of identified transport modes
Direct and Indirect

OUTPUT

Carbon emissions

Apply on

All transportation sectors – road, rail, urban transport, etc.

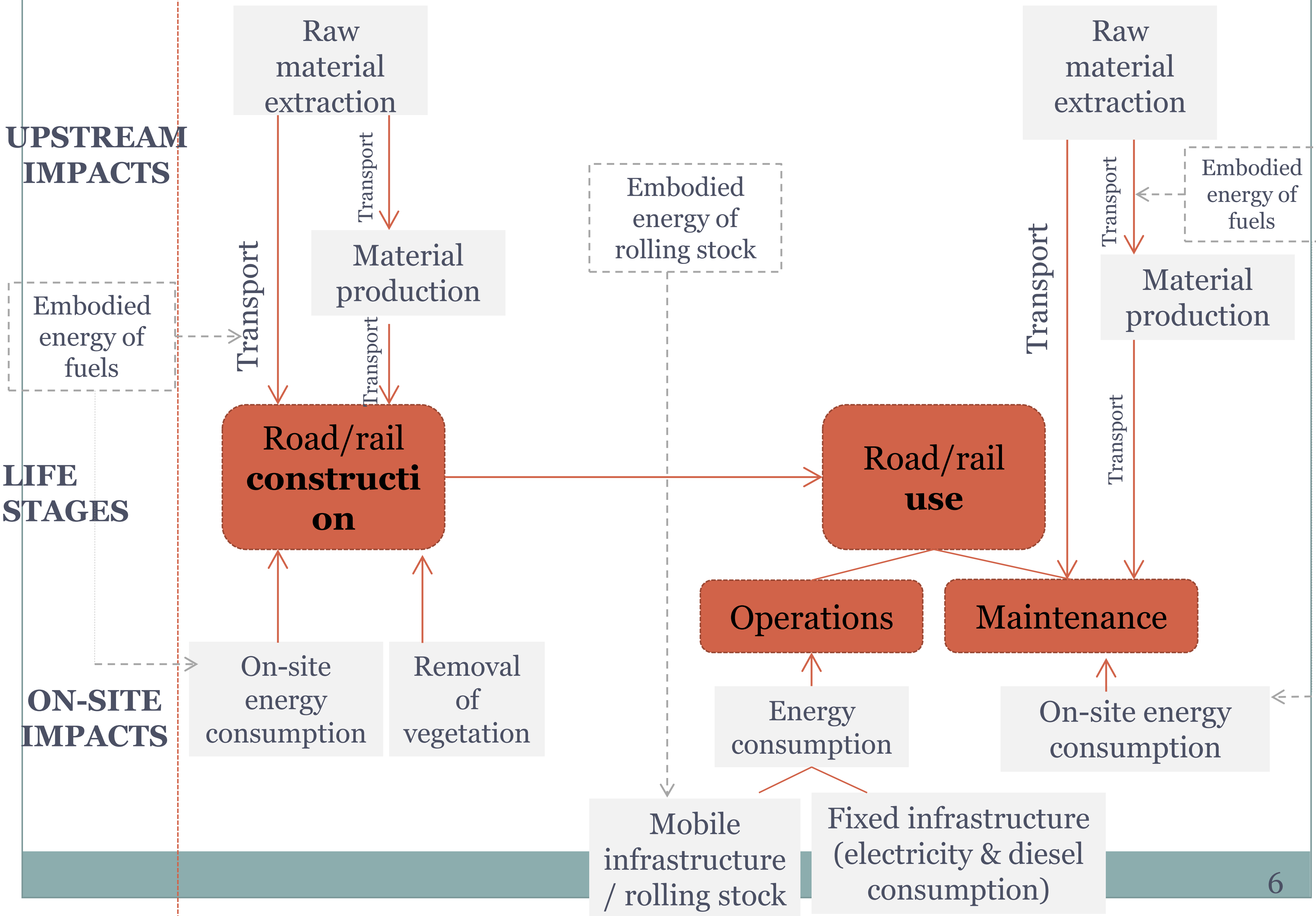
Key features of LCA framework developed

- Based on a detailed review of ISO 14000 framework, and of LCA studies recognized internationally (e.g. Chester and Horvath (2009), Birgisdóttir (2005), Stripple (2001))
- System boundary/scope has been defined/limited
- LCA framework follows a bottom-up approach, which is based on 'typical' projects rather than a sampling approach.
  - This is also an accepted international practice in LCA studies (Mroueh et al. (2000), Birgisdóttir (2005), NTUA (2006), Mroueh et al. (2001))

Key features of LCA framework developed

- India-specific spread sheet model developed
  - India-specific conversion factors used to the extent possible (Embodied energy and CO_2 values of materials and fuels; and tailpipe CO_2 emission factors of fuels)
- Study recognizes that technological and efficiency changes will take place in future. However, such efficiency improvements are not accounted while estimating the energy and CO_2 impacts for a 30 year period

System boundary



Scope of life cycle analysis

Direct energy and material consumption for construction, operation & maintenance

Production of construction materials

Transportation of construction materials

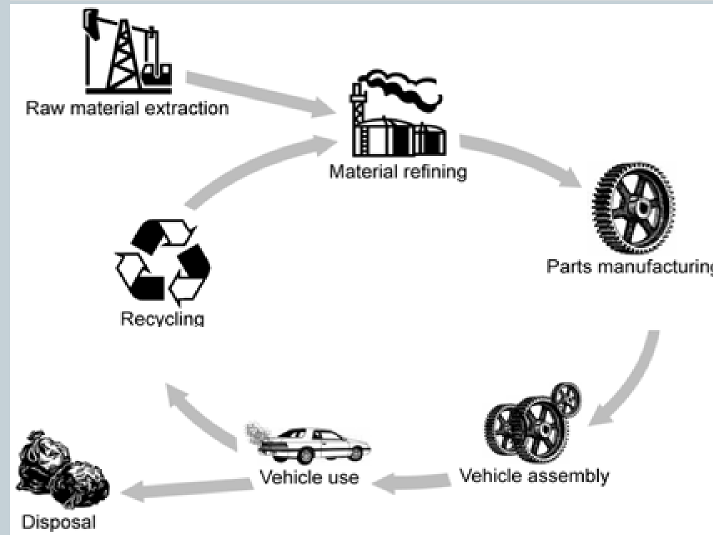
On-site Construction activity

BRTS
MRTS

Operations on the transport corridor

Maintenance of the transport corridor

Indirect energy and material consumption for manufacture of vehicles



Source- O'Brien et al (2001)

Bus
Rail coach
(Metro)

Indirect energy consumption for production of fuels like petrol and diesel

Petrol, Diesel, CNG, Electricity

Source- Wang M et al (2007)

Methodology

- Define LCA framework/define system boundaries
- Scope of the study: identified data inputs required
- Collected data from
  - Literature
    - Embodied energy of materials, fuels, vehicles
    - Operational energy consumption
  - Primary sources
    - Construction and maintenance data for select projects
- Data analysis - developed spreadsheet tool

Scope of the research work

- LCA conducted for -
  - Bus Rapid Transit System (BRTS)
  - Metro Rail Transit System (MRTS)

Data sources

Data required for *construction phase* LCA

- Volume of all materials consumed during required for per km
- Total amount of fuel consumed for the movement of materials (mode of transport, average loading, no. of trips, etc.)
- Total energy consumed on-site for per km construction of the selected projects
- Consumption of petroleum products

Construction data collected for

System	Project
BRTS	Pirana–Naroda stretch covering a total length of 25.4 km in Ahmedabad
MRTS	New Ashok Nagar-Noida line of Delhi metro rail (elevated section)

Data sources

Data required for *operations phase* LCA

- Energy consumption and CO_2 emissions due to movement of rolling stock (direct) and manufacture of rolling stock (indirect) are included in the LCA

Operations data collected for

System	Type of data collected	Source of data
Metro rail	Energy consumption by Delhi Metro	PDD (Project Design Document) submitted by DMRC to UNFCCC (to get carbon credits for Phase-2 of Delhi Metro)
BRTS	Energy consumption data for Ahmedabad BRTS	Data provided by CEPT, Ahmedabad

Data sources

Data required for *maintenance phase* LCA

- Energy and CO_2 emissions on account of *annual* and *periodic* maintenance are included in LCA
- Data related to material required, fuel consumed (on-site and transportation of materials/manpower, etc.), embodied energy of materials, etc. was collected

Maintenance data collected for

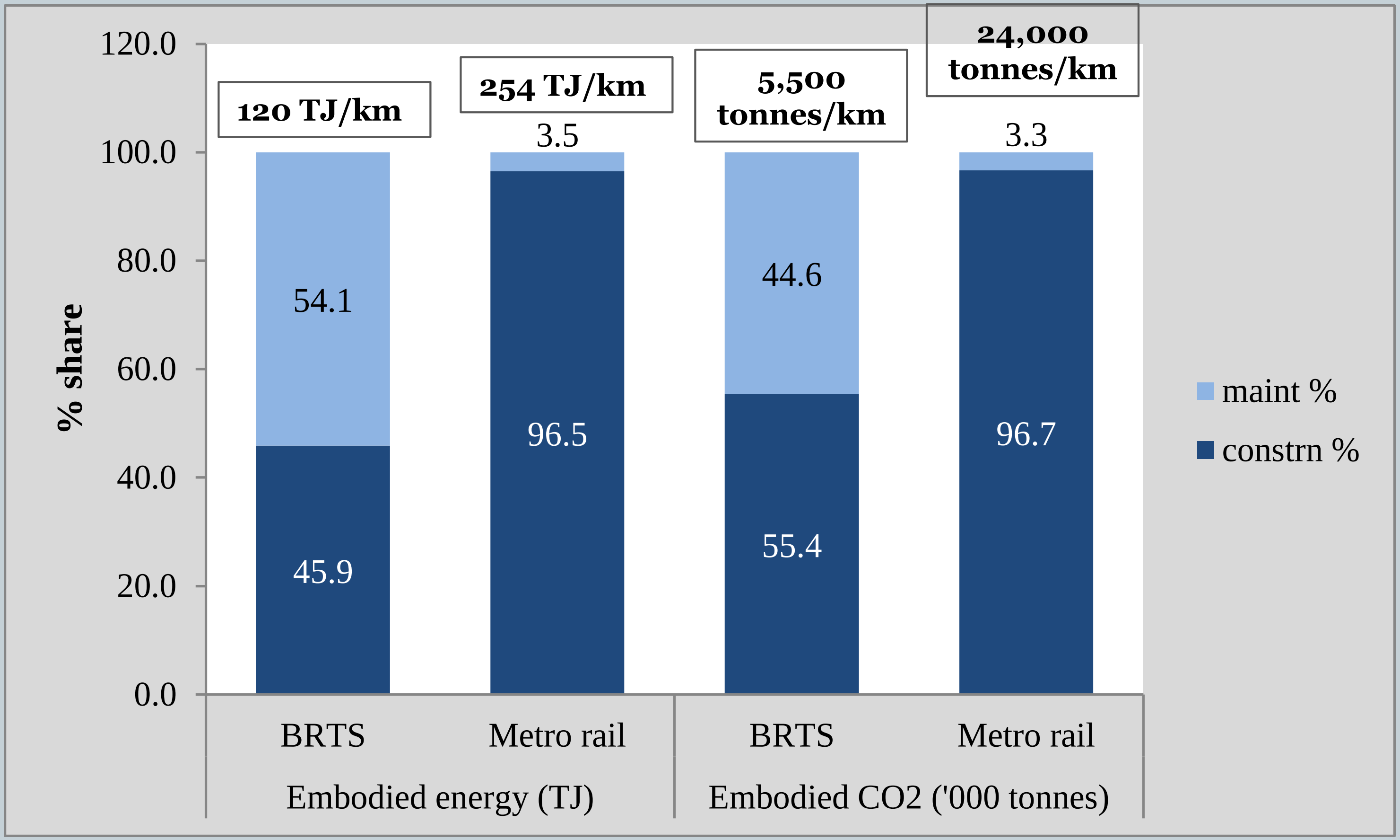
System	Project
BRTS	Periodic maintenance involves adding a renewal coat to the wearing course/surface at a pre-defined interval/frequency
Metro rail	Periodic maintenance or replacement during the 30 year life of the project

Note: It was assumed that the annual maintenance activity will remain the same for all years

Findings

Energy consumption and CO_2 emissions for public transport projects

Findings
Construction and maintenance phases



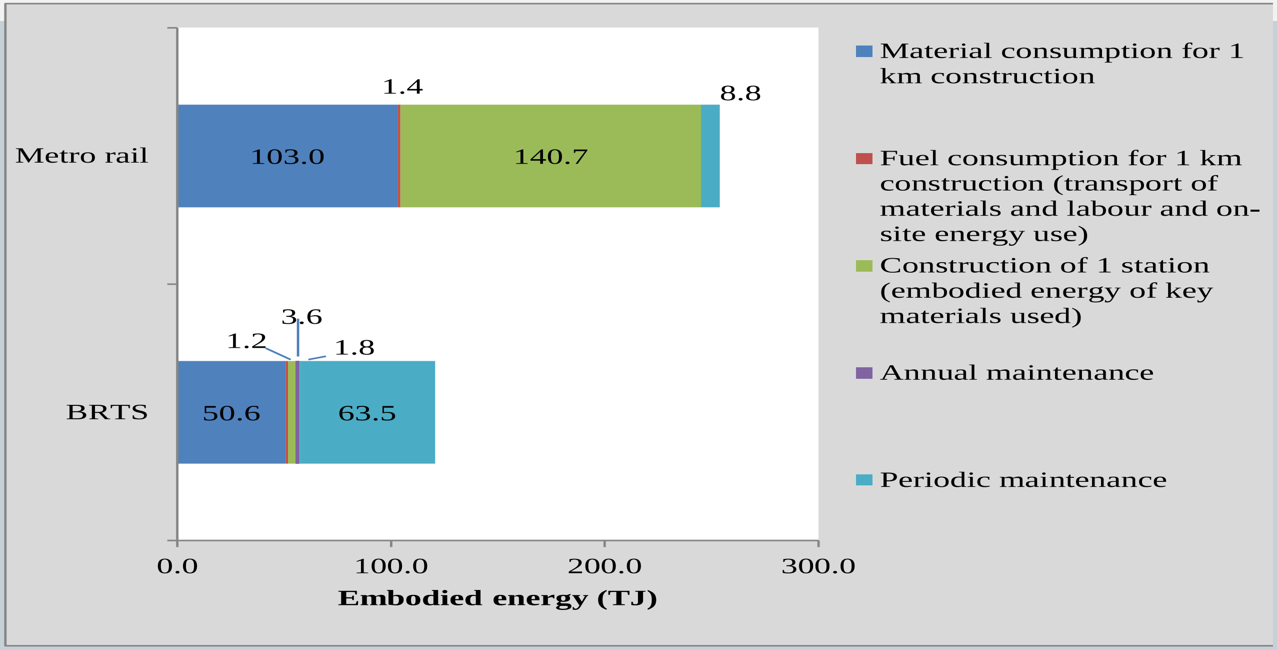
Share of construction and maintenance related activities in embodied energy and embodied CO_2 of urban transport projects (Source: TERI Analysis)

Findings

Construction and maintenance phases

Category-wise embodied energy

- Metro rail is the more energy and carbon intensive mode of transport
- Total embodied energy on account of constructing and maintaining per km of metro rail has been estimated at 254 TJ as compared to 120 TJ for per km of BRTS

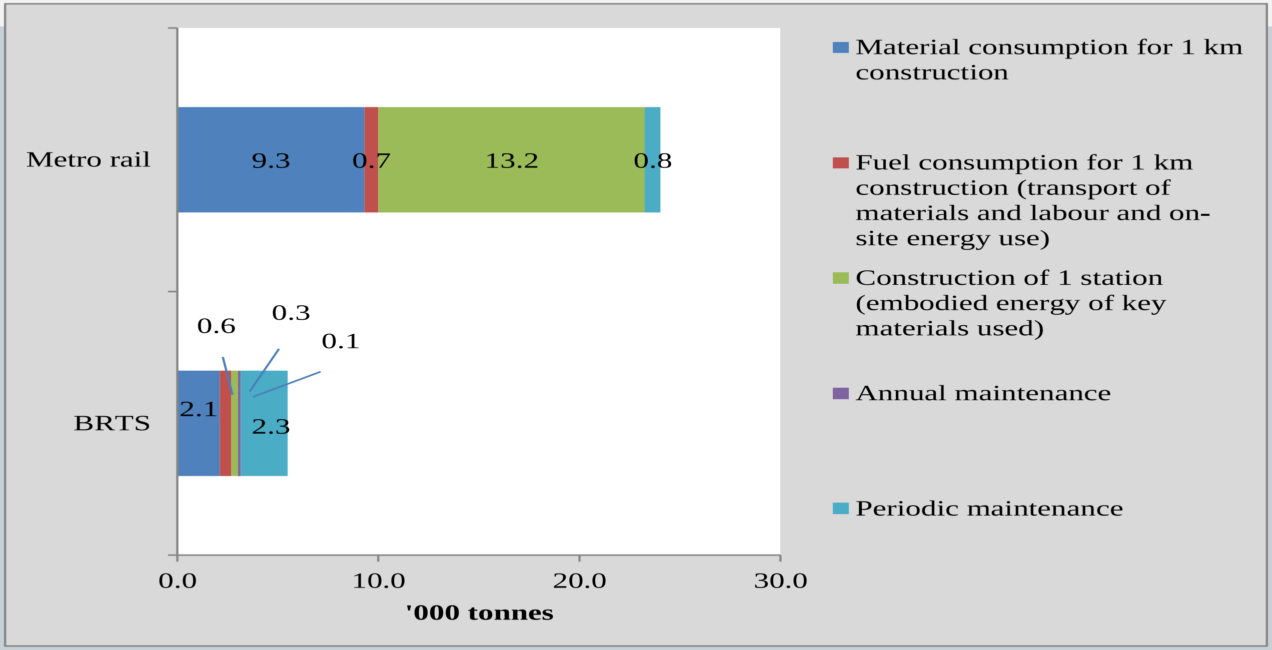


Energy consumption on account of construction and maintenance work for a period of 30 years (TERI Analysis)

Findings
Construction and maintenance phases

Category-wise CO_2 emissions

- Embodied CO_2 emissions for constructing and maintaining per km of metro rail for a period of 30 years stood at 24,000 tonnes
- 5,500 tonnes for constructing and maintaining 1 km of BRTS

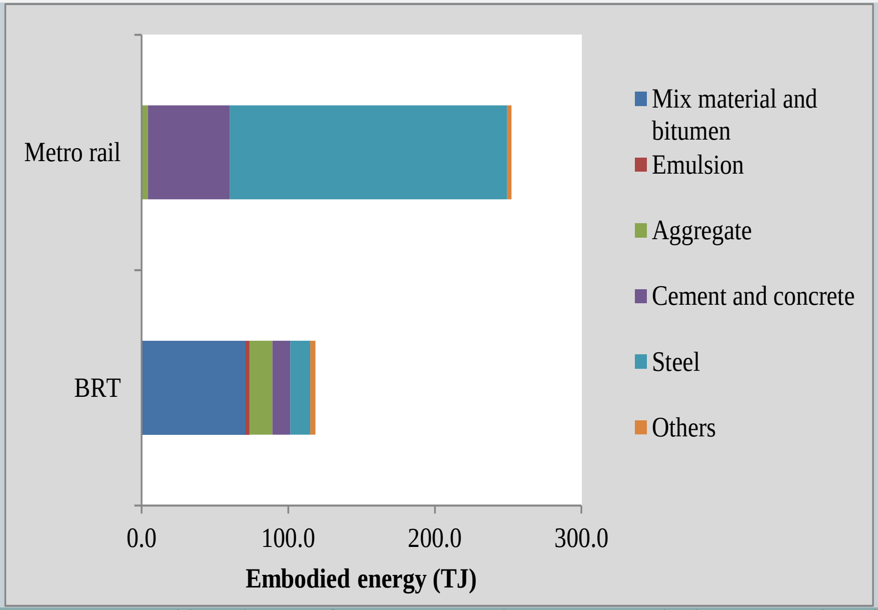


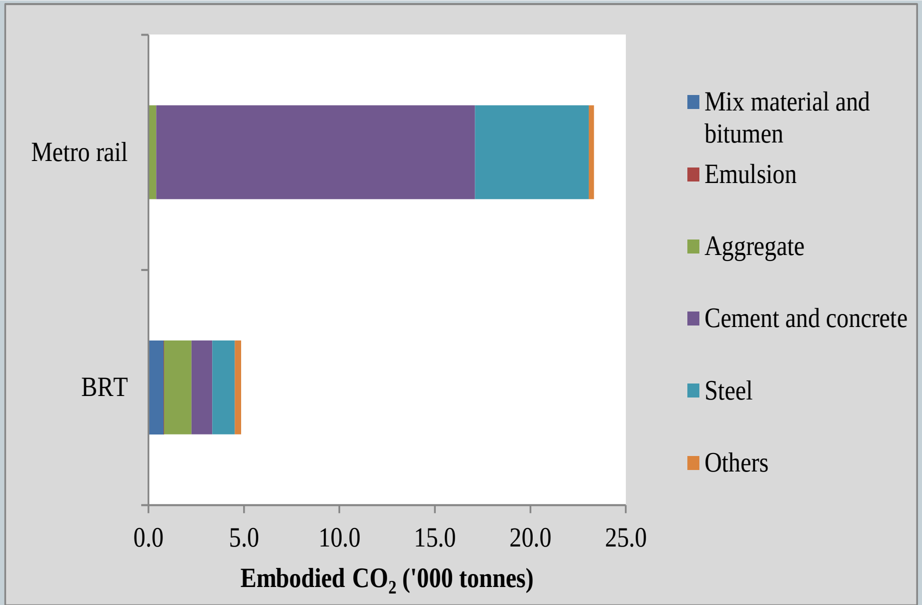
CO_2 emissions on account of construction and maintenance work for a period of 30 years (TERI Analysis)

Findings
Construction and maintenance phases

Material-wise

- High usage of energy and carbon intensive materials like steel & cement in MRTS
- With MRTS, construction of stations is more energy and CO_2 intensive as compared to construction of tracks
- Bitumen and aggregate are the most energy and carbon intensive materials used during construction and maintenance of BRTS

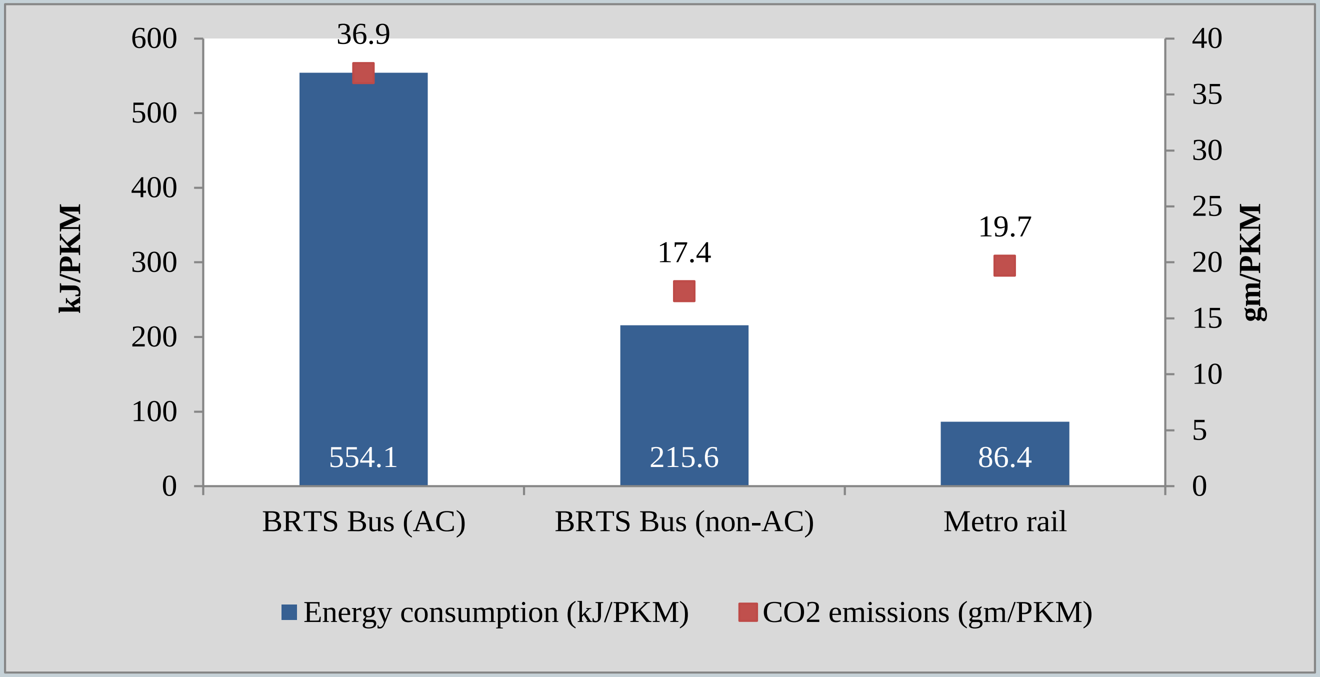




Contribution of construction materials to embodied energy and CO_2 emissions of construction and maintenance activities for 30 year period (Source: TERI Analysis)

Findings
Operations phase

- On a PKM basis, metro rail is the energy efficient mode of urban transport
- Within BRTS, air-conditioned (AC) buses account for more than twice in terms of both energy consumption and CO_2 emissions



Energy consumption and CO_2 emissions on account of BRTS and MRTS operations (Source: TERI Analysis)

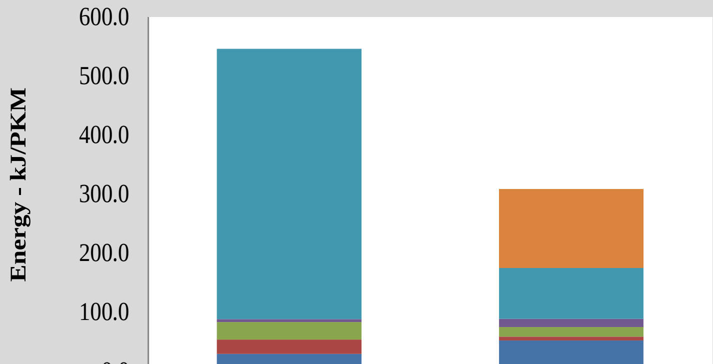
Calculating full life cycle emissions

Assumptions

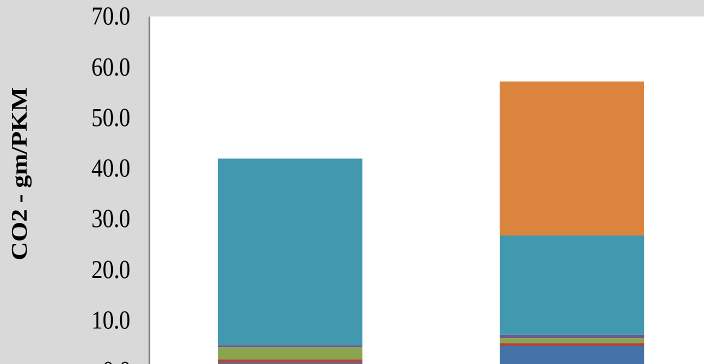
Transport system	Assumption
BRTS	• Total life of the fixed infrastructure (bus stops and bus lanes) taken as 30 years • Total life of rolling stock (buses) taken as 15 years • Calculations done for entire planned BRT corridor (129 km) with 249 bus stops. The operational length, at the time of analysis, was 67 km • Total number of buses deployed on commissioning taken as 737 • Passenger km estimated based on the design capacity of the Ahmedabad BRTS system (1.03 million passengers per day)
MRTS	• Total life of the fixed infrastructure (stations and viaducts) taken as 100 years • Total life of rolling stock (metro coaches) taken as 30 years • Calculations done for Phase I and II of Delhi metro (189.7 km track length) with 142 stations • Total number of trains plying under Phase I and II taken as 208 • Passenger km estimated based on the average ridership of 1.5 million/day

Findings

- Full life cycle energy intensity of Delhi MRTS is far less than the energy intensity of BRTS. However, metro rail system is more CO_2 intensive on account of the high carbon intensity of electricity



	BRTS	Metro rail
Operations- stations	0.0	133.4
Operations	458.1	86.4
Rolling stock maintenance	4.7	13.8
Rolling stock manufacture	29.6	16.3
Maintenance	24.4	6.5
Construction	29.3	51.9



	BRTS	Metro rail
Operations- stations	0.0	30.4
Operations	36.9	19.7
Rolling stock maintenance	0.4	0.6
Rolling stock manufacture	2.4	1.0
Maintenance	0.7	0.6
Construction	1.6	4.9

Life cycle inventory - Results for Delhi MRTS and Ahmedabad BRTS projects (Source: TERI Analysis)

Conclusions

- Application of the LCA methodology indicates that LCA is doable for transport projects
- Besides financial and technical feasibilities, full life cycle energy and CO_2 emission inventories should be drawn up and these taken into account while making investment decisions
- Efficient construction machinery and alternative sources of energy to run them can also help reduce energy and CO_2 impacts during construction and maintenance
- Maintenance activities are usually not given adequate attention in India
- This could help project developers in identifying less-energy and CO_2 intensive materials and processes

Conclusions

Framework can also be used to identify energy and CO_2 savings from:

- Reducing energy and CO_2 intensity of conventional materials used
- Using alternative construction materials
- Using locally available materials
- Using energy efficient processes and machinery
- Optimizing resource utilization
- Improving efficiency of rolling stock, and
- Reducing energy and material intensity during manufacturing and maintenance of rolling stock

Thank you

Akshima T Ghate
Senior Fellow & Associate Director,
Email: akshima@teri.res.in
TERI

Sharif Qamar
Associate Fellow,
Email: sharif.qamar@teri.res.in
TERI

Details of BRTS project

Project:	A total of 25.4 km of Ahmedabad BRTS construction covering: ▪ Pirana–Danilimda–Maninagar–Narol stretch (12 km) ▪ Narol-Naroda stretch (13.4 km)
City, State:	Ahmedabad, Gujarat
Total distance:	25.4 km
BRTS length constructed as on date when construction data was collected:	25.4 km
Construction duration:	Start date- 8th Aug, 2007 End date- 15th December, 2010
Design life of pavement (years):	Bus lane: 25 years Private vehicle lane: 25 years Cycle track: 25 years Footpath: 5 years
Cross-section details	ROW varies from 25 m to 60 m

Details of MRTS project

Name of the project:	Delhi Metro Rail project		
City:	New Delhi		
Metro rail start and end points:	From- New Ashok Nagar (Delhi)	To- Sector 32 (Noida)	Total distance between the two points (km): 7.2 kms
Construction duration:	Start date- August, 2006 End date- November, 2009		
Design life of rails: **Design life of viaduct:**	30 years 100 years		
Cross-section details:	Box girder with top slab width of girder - 9.1 m, height of box girder- 2.25 m, height of rail level above the existing road level - 9.8 m		