ENVIRONMENTAL SUSTAINABILITY

OF DIFFERENT PUBLIC MODES OF

TRANSPORT IN MUMBAI

Submitted

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1. Introduction

Cities all over the world especially in developing countries have witnessed rapid population growth. In India the population of the people residing in urban areas according to the 2001 census was 28.53% and is now currently 34% in 2019 and by 2030, 40.76% of the population is expected to reside in urban areas (World Bank Group, 2018). With such rapid urbanisation, there is a growing demand for a good transportation system. Consequently, urban areas face a huge mobility and transport challenges and at the same time there is again the problem of rising environmental, social and economic footprint as the urban transportation sector expands (Stjernborg and Mattisson, 2016) especially in metropolitan cities like Mumbai. The Table 1.1 various transportation impacts.

Table 1.1 Transportation impacts (Litman and Burwell, 2006)

Environmental	Economic	Social
Air pollution	Accessibility quality	Equity/fairness
Noise pollution	Traffic congestion	Impacts on mobility disadvantaged
Climate change	Infrastructure costs	Affordability
Water pollution	Consumer costs	Human health impact
Hydrologic impacts	Mobility barriers	Community cohesion
Habitat and ecological degradation	Accident damages	Community liveability
Depletion of non-renewable resources	Depletion of non-renewable resources	Aesthetics

The transport sector is responsible for a quarter of global energy-related greenhouse gas emissions and these are expected to grow substantially in the coming years. Sustainable transport achieves better integration of the economy while respecting the environment, improving social equity, health, resilience of cities, urban-rural linkages and productivity of rural areas (United Nations, 2017).

The public transport presents several benefits like environmental sustainability by reducing the demand for fossil fuels, economic benefits like transporting people to and from work and by reducing congestion and social benefits by providing access to different age groups (Stjernborg and Mattisson, 2016). Hence, public transportation is often framed as a key component of building sustainable cities. Therefore, it becomes imperative to assess the performance of different public modes of transport on the basis of suitable sustainable indicators which will help policy makers to make suitable improvements in different dimensions and this will lead to sustainable transport planning.

Therefore, in this report the sustainability of various public modes of transport in Greater Mumbai region which are the suburban rail, the metro, monorail and the buses plying within the administrative boundaries of the city are considered. The environmental sustainability indicator used is the kg CO_2 emissions per passenger km to assess the sustainability of different public modes of transport. Total kg CO_2 emissions per year due to these public transport is also calculated to determine the social cost of emissions.

The following sections focusses on the details of the public transportation within the cities followed by calculations and policy suggestion to make public transport more sustainable.

2. Public Transport in Mumbai

Mumbai being the commercial capital experiences high daily commute and is undoubtedly one of the most crowded cities in the world. As of 2015, 52% of commuters use public transport (Rao, 2016).

The bus service is run by Brihanmumbai Electric Supply and Transport (BEST) Company and has a vast network connecting different corners of the city.

The Mumbai suburban railway is one of the most economical transport. With a length of 430 km, it has the highest passenger density in the world, 7.5 million people daily (CAPA, 2011). At present it has 4 radial lines. These are

Western – From Churchgate to Dahanu Road

Central – From Chatrapati Shivaji Maharaj Terminus (CSMT) to Kasara/Khopoli

Harbour – From CSMT to Panvel/Goregaon

Trans-Harbour – From Thane to Vashi/Panvel

At present the metro line 1 is in operation. It is an 11.4 km line fully elevated and consists of 12 stations from Ghatkopar to Versova (MMRDA, 2020a). The mono-rail is the third largest monorail in the world. The line 1 connects Jacob circle in South Mumbai with Chembur in Eastern Mumbai.

3. Calculations and results

The objective here is to calculate the emission factors followed by total emissions and finally the social cost of carbon emissions due to the different public transport modes

3.1. Calculation of emission factors

In this section, the emission factors are first determined for different public transport as per the guidelines given in India GHG Program (2015).

3.1.1. BEST buses

Mileage of diesel BEST buses = 3 km per litre (Rao, 2016)

Mileage of CNG BEST buses = 2 km/kg (Banerjee, 2016)

The total passenger capacity of a BEST bus is 60 (40 sitting and 20 standees). During peak hours the passenger capacity exceeds way beyond 60 and during non-peak hours the capacity may be as low as 10 – 15. Hence, average capacity of 30 is considered. The Table 3.1 shows the emission factors for different fuel type

Table 3.1 CO2 emission factor for different fuel type (De Gruyter et al., 2017)

Fuel Type	CO2 EF (t/TJ)
Diesel	74.10
CNG	56.10

Calorific value of 1 l diesel is 45.0 MJ/kg = 37.3 MJ/l (density 0.83 kg/l) and calorific value of 1 l Natural gas is 46-49 MJ/kg. The formula used to determine the emission rate is given by Equation 3.1.

$$\text{Emissions} = \text{Fuel Consumed} \times \text{Emission Factor} \qquad (3.1)$$

Hence, emission rate due to CNG is calculated as

$\Rightarrow$ ½ (kg/km) X 47.5 (MJ/kg) X $56.1/10^6$ (t/MJ) = 0.001332 ton CO2/km = 1.332kg CO2/km

Emission factor for CNG BEST bus = $\frac{1.332}{30}$ = 0.0444 kg CO2/pax-km

Similarly, emission rate due to diesel

$\Rightarrow$ 1/3 (l/km) X 37.3 (MJ/l) X $74.1/10^6$ (t/MJ) = 0.000921 ton CO2/km = 0.921kg CO2/km

Emission factor for diesel BEST bus = $\frac{0.921}{30}$ = 0.0307 kg CO2/pax-km

3.1.2. Suburban rail

Fuel Consumption (Electricity) = 18.9 KWh/1000 GT-km (Ministry of Railways, 2018)

Tare Weight of one coach = 50 tonnes (Ministry of Railways, 2018)

Assuming extra 10 tonnes due to passenger load, total weight of single coach = 60 tonnes

Therefore, for a 12 coach passenger train, weight = 60 X 12 = 720 tonnes

Tonnes kilometre for one kilometre = 720 X 1 = 720

Fuel consumption = $\frac{18.9 \text{ X } 720}{1000}$ = 13.608 KWh

Average electricity emission factor in Maharashtra = 1.20 kg CO2/KWh (cBalance Solutions Pvt. Ltd., 2009). This gives us the total CO2 emissions = 13.608 X 1.20 = 16.330 kg CO2.

Passenger carrying capacity of 12 coach trains is 1,174 but during peak hours, it cross 6000 passengers. Hence, assuming an average passenger capacity of 3500 (Mirror Now Digital, 2019)

Hence, passenger km = 3500 X 1 = 3500

Emission factor for 12 coach train = $\frac{16.330}{3500}$ = 0.0046 kg CO2/pax-km

Emission factor for 15 coach train = $0.0046 \times \frac{15}{12}$ = 0.0057 kg CO2/pax-km

3.1.3. Metro

For a 4 car rake running 400 km, it requires 6300 kWh of energy including both traction as well as non traction purposes (Tejonmayam, 2018).

Therefore, per km electricity consumption = $\frac{6300}{400}$ = 15.75 kWh/km

The electricity emission factor in Maharashtra = 1.20 kg CO2/kWh (cBalance Solutions Pvt. Ltd., 2009). Passenger capacity of a 4 coach train = 1178 (MMRDA, 2020b)

Emission factor for 4 coach metro = $\frac{15.75\ (\frac{kWh}{km}) \times 1.20\ (kg\frac{CO_2}{kWh})}{1178}$ = 0.016 kg CO2/pax-km

Emission factor for a 6 coach metro = $0.016 \times \frac{6}{4}$ = 0.024 kg CO2/pax-km

3.1.4. Monorail

Assuming the same energy consumption rate as metro that is 15.75 kWh/km for monorail. The electricity emission factor in Maharashtra = 1.20 kg CO2/kWh.

Passenger capacity of the 4 coach monorail is 540 but at present an average of only 170 passengers are being transported (TOI, 2020).

Emission factor for 4 coach monorail = $\frac{15.75\ (\frac{kWh}{km}) \times 1.20\ (kg\frac{CO_2}{kWh})}{170}$ = 0.111 kg CO2/pax-km

3.1.5. Results

The table 3.2 shows the kg CO2 emissions per passenger km for different modes of public transport obtained from the calculation of emission rates.

Table 3.2 Kg CO2 emissions for different public transport modes

Mode of Transport	Kg CO2 per passenger km
BEST buses (diesel)	0.0307
BEST buses (CNG)	0.0444
Suburban rail (12 coach)	0.0046
Suburban rail (15 coach)	0.0057
Metro (4 coach)	0.016
Metro (6 coach)	0.024
Monorail	0.111

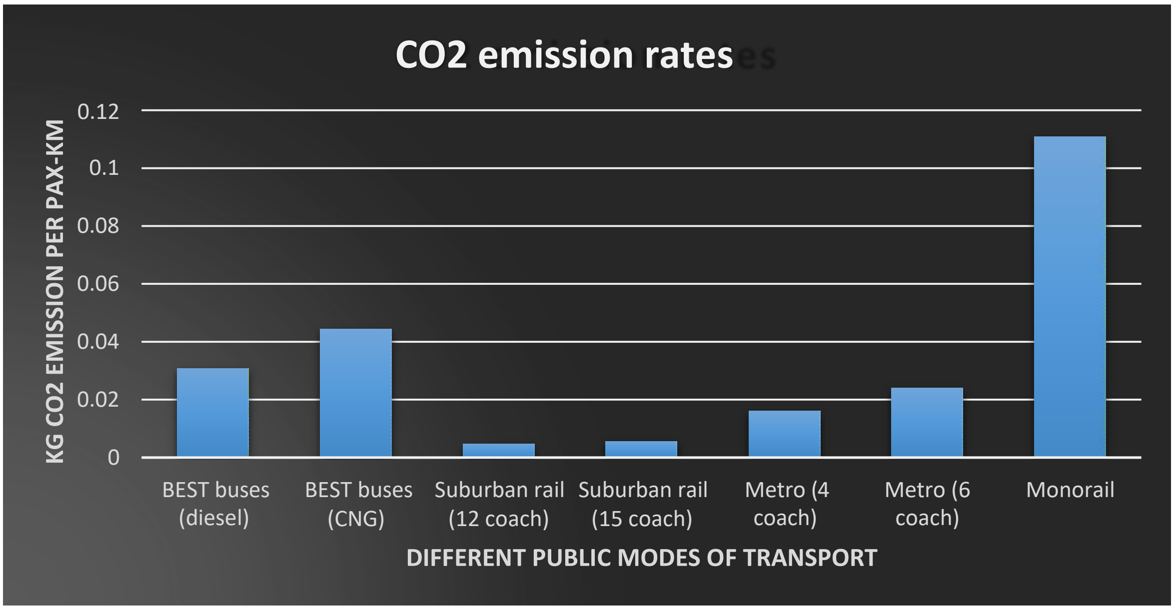

Figure 3.1 Bar chart showing emission factors for different public transport

The Figure 3.1 shows the kg CO2 emissions per passenger km for different public transports. It can be seen that suburban rails have the lowest emission factors whereas monorail has the highest and hence, suburban rails are the most sustainable mode of transport.

3.2. Calculation of total emissions

If the total distance travelled by the different public transport per day and the average passenger capacity is known, then the total CO_2 emissions of different transport modes per day can be calculated as given by Equation 3.2

$$\begin{aligned}\text{Per day CO2 emissions} \\ &= \text{Emission Factor of different public transport} \\ &\times \text{daily distance covered (km)} \\ &\times \text{average passenger capacity}\end{aligned} \tag{3.2}$$

Table 3.3 Emission factor, distance and passenger for BEST buses

	BEST buses (diesel)	BEST buses (CNG)
Emission Factor	0.0307	0.0444
Distance travelled (km)	Average total distance travelled by a bus in a day X number of buses (assuming 2/3rd of the fleet size) =160 (Sen and Badgeri, 2019) X 2/3 X 1329 (Mirror Now Digital, 2018) = 1,41,760	Average total distance travelled by a bus in a day X number of buses (assuming 2/3rd of the fleet size) =160 (Sen and Badgeri, 2019) X 2/3 X 2002 (Mirror Now Digital, 2018) = 2,13,547
Average passenger capacity	30 (based on assumptions)	30 (based on assumptions)

Total distance travelled by suburban trains (Central Railway and Western Railway) = 1,14,084 train km (NDTV, 2014). Since exact number of 12 coach and 15 coach trains are not available, assuming the average emission factor = $\frac{12 \text{ X } 0.0046+15 \text{ X } 0.0057}{(12+15)}$ = 0.0052

Table 3.4 Emission factor, distance and passenger for suburban trains

	Suburban trains
Emission Factor	0.0052
Distance travelled (km)	1,14,084
Average passenger capacity	3500

Table 3.5 Emission factor, distance and passenger for Metro

	Metro (4 coach)
Emission Factor	0.016
Distance travelled (km)	Distance between Ghatkopar and Versova X Number of trips = 11.4 X 370 (Mehta, 2017) = 4218
Average passenger capacity	1178

Table 3.6 Emission factor, distance and passenger for monorail

	Monorail (4 coach)
Emission Factor	0.016
Distance travelled (km)	Distance between Jacob circle to chembur X Number of trips = 19.54 (Thakkar, 2019) X 79 = 1544
Average passenger capacity	170

Based on the above information about emission factor, total distance covered per day and the average passenger from the Table 3.3, 3.4, 3.5 and 3.6 for BEST buses, suburban rail, metro and monorail respectively, equation 3.2 is used to calculate the per day kg CO2 emissions and the result of which is shown in Table 3.7

Table 3.7 Per day CO2 emission factor

Mode of transport	CO2 emissions per day (tonnes)
BEST buses (diesel)	135.17
BEST buses (CNG)	195.48
Suburban trains	2076.33
Metro	79.50
Monorail	29.12
Total	2515.6

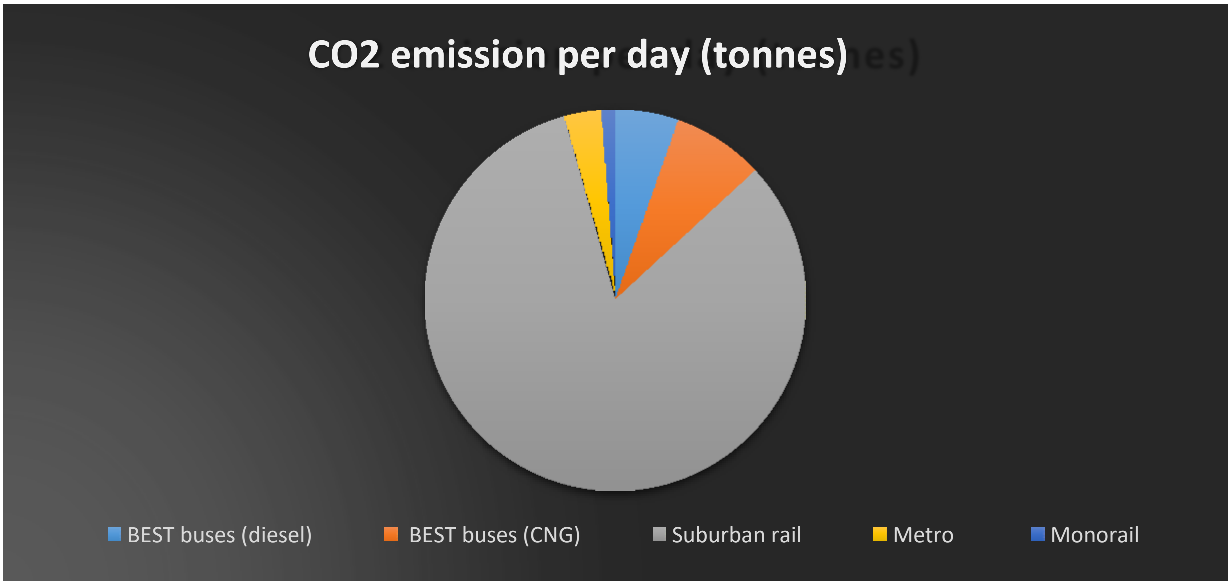

Figure 3.2 Pie chart showing per day CO2 emission for different public transport

From the calculations, we see that the though suburban rails have the highest per day CO2 emissions but the emission rate is the lowest for suburban train due to the large passenger volume it carries.

3.3. Social cost of carbon

The social cost of carbon (SCC) is the monetary cost of the damages to the environment due to emission of one ton of greenhouse gases in the atmosphere. The SCC puts the climate change impacts into economic terms to help policy and decision makers understand the impacts of GHG emissions. One of the ways in which SCC can be used in policy making is through benefit-cost analysis. A benefit-cost analysis compares the economic benefit of a proposed policy to its implementation costs. For example a policy that restricts air pollution – the economic benefits due to improvement in public health as a result of cleaner air and reduction in environmental damage is compared against the cost of equipment to reduce air pollution (Rennert and Kingdon, 2019).

India's SCC emissions was estimated to be the highest at 86 USD per tonne of CO2. This implies that each additional emission of a tonne of CO2 will result in an economic loss of $86. India is followed by US and Saudi Arabia where the SCC emissions is $48 per tonne and $47 per tonne respectively. The CO2 emissions are costing the Indian economy up to $210 billion per year (Maurya and Goswami, n.d.).

In our case the social cost of carbon emissions due to the different public transport per year in the Greater Mumbai is calculated as

⇒ Total CO2 emissions per day X 365 X SCC for India

⇒ 2515.6 (tonnes/day) X 365 (days) X 86 (USD/tonne) = $78,964,684 per year = 585,59,97,276.03 INR

Hence, approximately 585 crore INR per year is incurred due to CO2 emissions from public transport in Greater Mumbai.

4. Policy suggestions

The current public transport system can be further enhanced to make it more sustainable option. Here are few suggestions

(i) Although the current suburban trains are the best transport modes in Mumbai, safety in local train is a major concern. Suburban trains are jam-packed during peak hours and there have been incidences of people falling from the train. As a result, people hesitate to travel through suburban trains. Increasing the safety will further attract commuters to use suburban trains.

(ii) Changing to better fuel types which have low CO2 emission factor (ton/TJ) like CNG can help reduce the overall CO2 emissions although in our case the kg CO2 emission factor for CNG was the highest due to the lower mileage it offered.

(iii) Public transport modes like metro and monorail which are comparatively more expensive than suburban trains observe low ridership. This can be avoided by reducing the fares of monorail and metro to the social welfare levels. This can encourage more people to shift to these transport modes from private vehicles as these are safe and offer comfortable ride.

(iv) Policies for improving the current public transport through regular maintenance can also significantly reduce the CO2 emissions.

5. Conclusion

Sustainable transport is the solution to the traffic problems of cities. Encouraging public transport over private transport can reduce various externalities associated with the increasing traffic like traffic congestion, air and noise pollution. Here the environmental sustainability of different transport modes were assessed based on the kg CO2 emissions. It was found out that suburban trains had the highest kg CO2 emission per day but had the lowest emission factor (kg CO2/pax-km). This can be attributed to the high passenger volume it carriers. The social cost of carbon emissions were also calculated and it was found out that Mumbai incurred approximately 585 crore INR due to CO2 emissions from public transport mode. Finally, few policies to improve and enhance the public transport modes and reduce the CO2 emissions were provided.

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