Development of Roadmap for Electrification of Freight Vehicles in Chennai

Authors

Gayathri R, Suby Charles, Vinoth Kumar L, Siddhartha MM, Rokom Perme, Surendra Reddy K, Gitakrishnan Ramadurai

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While shifting to cleaner vehicles is the need of the hour, the adoption of electric vehicles (EV) in India is still in a nascent stage. The government of India together with various departments such as the Ministry of Road Transport, Department of Heavy Industry, Ministry of Finance, and Ministry of New and Renewable Energy, has supported the electric mobility transition to reduce carbon footprint. Various policies and strategies have been devised by the government to motivate stakeholders (manufacturers, energy suppliers, consumers, etc) for adopting and shifting towards EV. Embracing EV for mobility would enable transformation to an urban eco-system of pollution-free transportation of people and goods.

The objective of this report is to explore the emergence of EV for urban freight delivery in Chennai city. A roadmap for the electrification of freight vehicles based on the data collected from field surveys is presented in this report. The roadmap focuses on emissions saved, the motivation, contribution and challenges of various stakeholders, power demand, and charging infrastructure required for the implementation of electric freight vehicles (EFV) in Chennai.

1. BENEFITS OF CONVERTING TO ELECTRIC VEHICLES- LIFE CYCLE COMPARISON OF GREEN HOUSE GAS (GHG) EMISSIONS FROM ICE DIESEL AND BATTERY ELECTRIC TRUCKS

Majority of the studies in the literature employ Cradle-to-Grave (C2G) assessment to compare life cycle emissions of ICE diesel vehicles with electric vehicles[1]. C2G assessment of emissions considers both the fuel and vehicle life cycle emissions and is more comprehensive than well-to-wheel assessment that considers only the fuel cycle. C2G assessment of emissions is superior to other LCA assessments for comparison of GHG emissions from vehicles with significant contributions in different stages. While the GHG emissions for BEVs have significant contributions during the electricity production, ICE vehicles contribute significantly to GHG emission during operation stage. Use of LCCA other than C2G thus may result in wrong conclusions on the feasibility of BEVs. For example, comparison of tail pipe emissions favour BEVs as they have zero-tail pipe emissions. In contrast, higher vehicle manufacturing emissions and Electric Vehicle Service Equipment (EVSE) manufacturing emissions may lead to higher emissions from BEVs. These are not accounted for in Well-To-Wheel analysis and thus may favour ICE diesel vehicles. We estimate the C2G GHG emission factors in CO2 equivalents for both diesel ICE vehicles and battery electric vehicles and use them to estimate the total emissions from freight trips generated by establishments in Chennai city. Subsequently, we estimate the emission savings possible by shifting to BEVs.

We estimate the GHG emission factors for BEVs for the present vehicle composition. The emission factors for BEVs are estimated for the present electricity generation mix (%) in India[2].

We consider emissions during vehicle manufacturing, fuel extraction, fuel processing, fuel transportation, vehicle operation (tailpipe emissions), and end of life emission savings for the emission factor estimation of ICE diesel vehicles. The emissions during the operation of diesel fuel vehicles are computed using the emission data obtained from our earlier study[6]. The emissions during diesel fuel extraction, processing and transportation are obtained from literature as 11,025 g CO_2e/GJ[3]. The vehicle manufacturing emissions and end-of-life value emission savings are calculated using the emissions produced per tonne data from literature[4], and the curb weight of vehicles.

For the case of GHG emission estimation of battery electric vehicles, we consider emissions during vehicle manufacturing, battery manufacturing, EVSE production, electricity production, and end of life emission savings. The present electricity mix (55.9% coal, 6.9%

[1] Mounisai Siddartha Middela, Srinath Mahesh, Surendra Reddy Kancharla, Gitakrishnan Ramadurai, Rokom Perme, Subrahmanya Kiran Sripada, Gayatri Devi. Estimating emissions from urban freight trips by combining real-world emission data and a city-wide establishment survey: Case study of Chennai, India. 2019

[2] Annual Generation Programme- 2019-2020, Central Electricity Authority, Grid operation and distribution wing, Operation performance monitoring division

[3] Jang, J.J., Song, H.H. Well-to-wheel analysis on greenhouse gas emission and energy use with petroleum-based fuels in Korea: gasoline and diesel. The International Journal of Life Cycle Assessment 20, 1102–1116 (2015)

[4] Lee et al. Electric Urban Delivery Trucks: Energy Use, Greenhouse Gas Emissions, and Cost-Effectiveness. Environmental Science & Technology 2013 47 (14), 8022-8030

natural gas, 1.9% nuclear, 12.6% hydro power, 0.1% petroleum, 23.4% renewable energy sources) is employed for calculation of emissions from electricity production[5]. We accounted for transmission and distribution losses of 21% for Indian grid, in the estimation. BEV manufacturing emissions and battery manufacturing emissions are calculated using curb weight and emissions per tonne of production. The end-of-life emission savings are also calculated using curb weight and production emissions per tonne weight of vehicles.

Further, to estimate the emissions from freight transport sector, we use the trip information such as number of trips and the average distance travelled by different vehicle types on a daily basis. The data is obtained from an Establishment-Based Freight Survey (EBFS)[6] conducted in Chennai in 2016. The total trip length travelled by trucks, pickups and three-wheelers is estimated for the freight trips generated at establishments. These include those that either originate or terminate at establishments. The total trip length of trucks, pickups and three-wheelers is multiplied by the corresponding GHG emission factor as shown in table 3, to obtain the total GHG emissions with ICE diesel vehicles. The corresponding emissions and emission savings in CO_2 equivalents are also estimated for the case of BEVs displacing 100% ICE diesel vehicles.

Though the C2G emissions of electric vehicles are less than that of ICE vehicles (80% reduced as shown in table 3), it still is significant. Significant amount of emissions are generated from the time of battery production during the process of manufacturing and assembling. Manufacturing batteries using renewable energy sources can substantially reduce battery emissions which will, in turn, reduce C2G emissions.

Table 1: Estimation of C2G emissions for freight trips in Chennai city by vehicle type

Freight trips generated	Vehicle type	Total Distance (km)	ICE		EV	
			Emission factor (g/ km)	Emissions CO_2 eq. (ton)	Emission factor (g/ km)	Emissions CO_2 eq. (ton)
Freight trips produced	Trucks	125,941	1,618	204	804	101
	Pick ups	389,812	1,416	552	158	62
	Three wheeler	300,979	132	40	77	23
Freight trips attracted	Trucks	118,994	1,618	193	804	96
	Pick ups	540,927	1,416	766	158	85

[5] Government of India, Central Electricity Authority, Executive summary on power sector, March 2020

[6] CoE-UT IIT Madras (2017). Towards developing a comprehensive planning framework for urban freight, Sponsored project by Shakti Sustainable Energy Foundation

Freight trips generated	Vehicle type	Total Distance (km)	ICE		EV	
			Emission factor (g/ km)	Emissions CO_2 eq. (ton)	Emission factor (g/ km)	Emissions CO_2 eq. (ton)
	Three wheeler	107,360	132	14	77	8
Total			1768 tonne		375 tonne	

C2G emissions associated with the fuel cycle of electric vehicles can be brought down by shifting to renewable energy sources and by providing incentives to install renewable energy sources such as solar panels.

2. ELECTRIFICATION OF URBAN FREIGHT – STAKEHOLDER'S ROLES AND CHALLENGES

Transition to EV - this new technology has been a big challenge for all stakeholders of automobile industries including the big players. The main stakeholders for electric freight vehicle mobility include i. shippers, ii. automobile manufacturers, iii. logistics operators, v. power utilities, vi. city and municipal corporation and vii. pollution control board and viii. traders/ truckers associations.

The table below describes the motivations, contributions, and challenges faced by different stakeholders towards electrification of urban freight.

Stakeholder	Motivations (what conditions/situations will motivate)	Contributions (different roles, actions to be performed)	Challenges (possible hurdles faced while performing actions)
Shippers	• Statutes asking a certain minimum portion of shipments to 'Go Green'. • Savings in cost by use of Electric freight Vehicles (EFV). • Incentives/Recognition for 'Green' shipments.	• Opt for logistics operators having EFV fleet. • Gradually increase the portion of 'Green' shipments over time. • Promote among fellow shippers.	• Reluctance to shift from age-old practices. • Absence of large and variety of EFV fleet to cater to different shipment types and sizes. • Do not have control over the choice of fleet type (as it is trucker's prerogative).
Logistics operators	• Attractive purchase plans (down payment, EMIs) for EFVs. • Financial incentive to overcome high EFV price. • Statutes to allow EFVs 24x7 in urban areas and exemption from taxes/tolls, parking fee. • Recognition. • Discounted power tariff. • Availability of charging/swapping infrastructure.	• Induct EFVs into the fleet. • Can promote shipments by EFVs to customers.	• Disposal of existing ICE fleet. • Lack of capital to buy EFVs. • Uncertainty over profit-making by use of EFVs.
Automobile Manufacturers	• Laws to make compulsory	• Offer EFVs. • Promote EFVs.	• Lack of market for EFVs (at least

Stakeholder	Motivations (what conditions/situations will motivate)	Contributions (different roles, actions to be performed)	Challenges (possible hurdles faced while performing actions)
	manufacturing/sale of certain no. of EFVs. • Recognition. • Availability of raw materials. • Mass production of EFVs	• Create awareness about savings in operating cost compared to ICE vehicles.	during the initial period). • Fast-changing EV technology. • Raw material availability.
Pollution control boards	• Reduction in GHG emissions.	• Awareness of the benefits of using EFV's. • Regular monitoring of pollution levels. • Emissions tax for polluting vehicles.	
City / Municipal Corporations	• Central and state funding tied to improvement in air quality	• Allow EFVs 24x7. • Ensure charging infrastructure.	
Power distribution companies	• Reduced operating cost by using supply from idle-vehicles' batteries. • Increased stability of the electricity supply network due to V2G supply as an auxiliary to renewable sources.	• Discounted fares for charging facilities. • V2G policy and tariffs.	• Upgradation of infrastructure. • User acceptance - needs demand-based dynamic tariff.
Trader associations / Chambers		• Educate/create awareness about savings in shipping costs by use of EFVs.	
Truckers associations	• Combined effect of government policies promoting EFVs and advantage of zero tailpipe emissions contribute to pollution control in urban areas as a societal responsibility. • Charging facility in	• Educate truckers about reduced operating costs by using EFVs, and about incentives.	

Stakeholder	Motivations (what conditions/situations will motivate)	Contributions (different roles, actions to be performed)	Challenges (possible hurdles faced while performing actions)
	loading docks		

3. ELECTRIC POWER REQUIREMENT FOR ELECTRIC FREIGHT VEHICLES IN CHENNAI

The limited availability of charging infrastructure currently is one of the major roadblocks to EV adoption in India. Prediction of energy demand for EV is essential for the utility companies to forecast energy consumption. Based on the forecast, the utility companies can analyse their generation capabilities to increase the power production and to determine the infrastructure and equipment to be installed or improved[7]. As per the estimated projection of growth in demand for EVs in the future "the overall electricity demand from electric vehicles in India is projected to be around 79.9 gigawatt hours by 2020 and is expected to reach 69.6 terawatt hours by 2030."[8]

Comprehensive Modal Emission Model (CMEM) was used to compute the electric power required for electric three-wheelers and pick-ups using the formula given below;

$$P = \frac{(\mathrm{Ma} \pm \mathrm{Mg}\sin\theta + \mathrm{Mg}\,C_r\cos\theta + 0.5C_d\rho A v^2)v + P_{acc}}{100\epsilon}$$

P: Engine power required in kW per hour

M: Total mass (vehicle's weight and weight of cargo)

A: Acceleration (taken as 0)

g: Acceleration due to gravity

ϴ: Grade= 0

C_r: Rolling resistance

C_d: Drag resistance

A: Frontal surface area

v: Velocity = 25 kmph (assuming that urban freight trips operate at this speed)

P_{acc}: Auxiliary power = 0

ϵ: Efficiency of electric motor

Table 4 shows the parameters used for computing the electric power requirement as per CMEM model.

Table 2: Parameters used for computing electric power requirement

Parameters	Three-wheeler	Pick-up
Mass of the empty vehicle	675 kg	1920 kg

[7]https://www.researchgate.net/publication/301406649_Estimation_of_electrical_energy_demand_by_electric_vehicles_from_households_A_UK_perspective

[8] Ministry of New and Renewable Energy Annual report 2019" by MNRE

Parameters	Three-wheeler	Pick-up
Payload	400 kg	1000 kg
Rolling resistance	0.028	0.02
Drag resistance	0.56	0.44
Frontal surface area	2009700 mm^2	2759680 mm^2

Electric power consumption per hour computed for pick-up and three-wheeler is 4.27 kW and 2.2 kW respectively as per CMEM model. Assuming a speed of 25 kmph for commercial vehicles in cities, the total time needed to cover the total trip distance (as given in Table 3) was computed. Total time multiplied by electric power consumption per hour calculated from CMEM model gives the total power requirement for each vehicle type.

Electric power consumption (kWh/mile) for trucks was taken as 1.59[9]. CMEM was not used to compute the electric power requirement of electric trucks since currently, they are not available in the Indian market. Table 5 shows the fuel consumed by ICE vehicles as well as electric power needed if ICE freight vehicles are replaced by electric freight vehicles in Chennai. To compute the fuel consumption of ICE vehicles, mileage for three-wheelers, pick-ups, and trucks was taken as 36 kmpl, 18 kmpl and 10.8 kmpl, respectively.

Fuel consumed in litres for ICE vehicles are computed using the formula given below;

$$\text{Fuel consumed by a vehicle type in litres} = \frac{\text{Total trip distance of that vehicle type}}{\text{Mileage of that vehicle type}}$$

For pickups and three wheelers,

$$\text{Electric power required by a vehicle type in kWh} = \text{Electric power consumption per hour for that vehicle type} \times \frac{\text{Total trip distance of that vehicle type}}{\text{Average speed within the city limits (i.e.25kmph)}}$$

For trucks,

Electric power required by a vehicle type in kWh = Electric power consumption per mile for trucks x Total trip distance of trucks

[9] IEA 2019 Report

Table 3: Fuel consumed for ICE versus electric power requirement for charging EFV

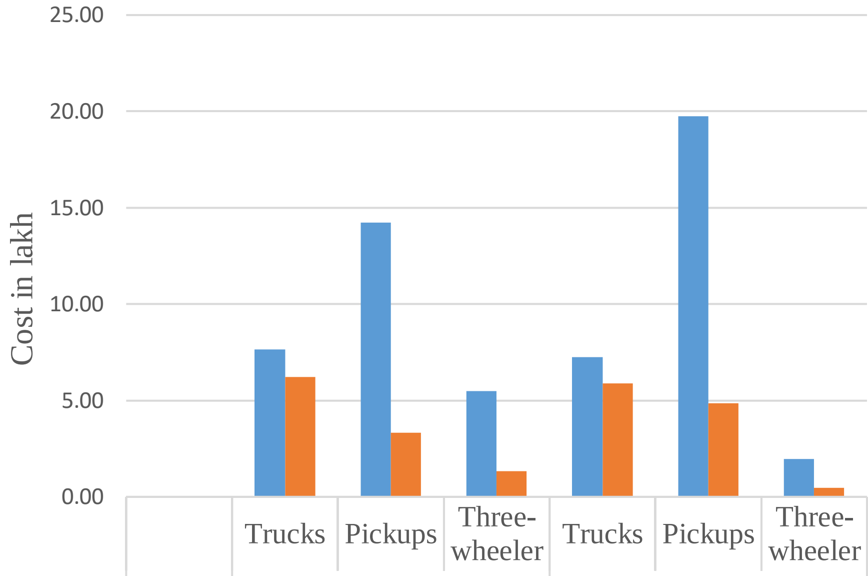
Freight trips generated	Vehicle type	Total trips (No.)	Total trip distance (km)	ICE	EFV
				Fuel consumed (litres)	Electric power required (kWh)
Freight trips produced	Trucks	11487	125941	11661	124427
	Pick-ups	65055	389812	21656	66580
	Three-wheeler	51466	300979	8361	26486
Freight trips attracted	Trucks	5472	118994	11018	117564
	Pick-ups	46258	540927	30052	97367
	Three-wheeler	13140	107360	2982	9448
Total Fuel/ Electric power required				85730 litres	442 MWh

In Tamil Nadu, power consumption is about 10000 million units in a month (as of February, 2020[10]) and for Chennai city, it is about 2000 million units.[11] As per our estimates, the power consumption by electric freight vehicles is estimated to be 13.26 million units in a month. (0.6% increase).

Figure 9 shows the cost comparison of diesel in case of ICE vehicles and electricity costs involved in charging as in the case of EFVs. Diesel cost is taken as Rs.65.68 per litre and electricity cost as Rs.5 per kWh. There is a 60% reduction in cost when shifting to EFVs. (*Note: Parking charge while charging an EFV is not considered*)

[10]https://timesofindia.indiatimes.com/city/chennai/tamil-nadus-power-usage-drops-by-14/articleshow/75385023.cms

[11]https://www.thehindu.com/news/cities/chennai/chennai-consumes-20-of-the-power-of-the-state/article5934753.ece



	Freight trips produced			Freight trips attracted		
	Trucks	Pickups	Three-wheeler	Trucks	Pickups	Three-wheeler
Cost of diesel for ICE vehicles	7.66	14.22	5.49	7.24	19.74	1.96
Cost of electricity for charging for EFVs	6.22	3.33	1.32	5.88	4.87	0.47

Figure 1: Cost comparison of ICE versus EFV (in lakh)

4. ESTIMATION OF THE NUMBER OF CHARGING STATIONS

Charging infrastructure plays a vital role in EV adoption, and the absence of a proactive plan impedes market adoption. The charging infrastructure includes all the hardware and software that is required for the safe transfer of electricity from the grid to the vehicle. FAME II has addressed the need for EV infrastructure, and each state has come up with the required number of charging stations. The question arises whether it is sufficient to meet the demand of electric vehicles in future. Therefore, the number of charging stations required for electric freight vehicles in Chennai was estimated.

Considering the following battery capacity - pick-ups-14.4 kWh and three wheelers- 4.8 kWh - and charging time for slow (8 hours for pick-ups and 2.67 hours for three wheelers) and fast chargers (1.8 hours for pick-ups and 40 minutes for three-wheelers) for electric freight vehicles available in the Indian market currently, the number of chargers needed were computed as shown in table 4. The time taken for fast charging is 75% less than that of slow charging, and so is the number of chargers. It was also assumed that the charging stations are available round the clock. (Note: Assumption based on which the estimation was made is that 100% of the freight vehicles in Chennai city are replaced with electric freight vehicles in the current scenario).

Table 4: Number of chargers needed per freight vehicle type

Vehicle type	Electric power required (kWh)	Time required for slow charging (h)	Time required for fast charging (h)	No: of slow chargers needed	No: of fast chargers needed
Trucks	241991	Not available	1315	Not estimated	55
Pick-ups	163947	91082	20493	3795	854
Three-wheeler	35934	19988	4641	833	193

As per the EV policy[12] it is expected that there would be a charging station for every 3 km grid in cities and 25 km on highways. Area of Chennai city is 426 km^2. Dividing Chennai city into 3km X 3km grids, the total number of charging stations planned to be installed are 47 which can serve only 4% of the total freight vehicles (assuming one fast charger per charging station and if 100% of electric freight vehicles uses public chargers). Improvement and focus on charging infrastructure is required to end the problem of range anxiety that the EV buyer faces while travelling for relatively long distances.

[12] https://pib.gov.in/newsite/PrintRelease.aspx?relid=193630

5. SUMMARY

The push to adopt EV in India would result in an eco-friendly transportation system and reduction in emissions. Various policy and adoption plans charted by GoI, together with the support from various stakeholders has contributed (and continue) to the smoother electric mobility transition. EV is a new technology and each stakeholder has roles and responsibilities to achieve the government target in terms of emission reduction and EV penetration for a greener India.

At present the government policy and subsidies support consumers to overcome cost hurdles and motivate them to purchase EV. However, for EV's to run smoothly Government of India (GoI) has to address the issue of inadequate infrastructure and the excess power supply-demand to feed the charging stations throughout the country.

The highlights of the roadmap for EFV implementation are summarised below:

- Implementation of EFV in Chennai would result in 80% reduction in emission of CO_2 contributed by freight vehicles. The analysis shows that the GHG savings from electric vehicle emission is significant than ICE. However, the cumulative air pollution from cradle to grave for EV and ICE has to be compared to understand the environmental benefits in shifting toward EV mobility.
- Based on the analysis of the survey data (i.e. number of freight trips and distance) about 442 MWh of power is required per day to charge EFVs in Chennai.
- About 1106 fast-charging stations are required to meet the charging demand for EFV in Chennai. Assuming only one charging station for every 3 km X 3 km grid would cater to only 4% of EFV in Chennai. Indian policymakers should explore options for alternative and transition to clean power sources, ways to control emission by setting up stringent emission standards, and fuel economy regulations.

As the next step in reducing emissions and encouraging cleaner vehicles, the government needs to explore and prioritise EV public transport and shared mobility options so that fewer commuters opt for private vehicles. In 2017 the share of CO_2 emissions from logistics was around 7% of the total CO_2 emissions in India[13]. Hence the GoI has to include policy and incentive schemes for EFVs explicitly in the FAME II. This would support and motivate stakeholders of the transport sector to embrace EFVs to reduce carbon emissions and air pollution caused by goods movement.

[13] Based on RMI's calculations and data collected from OECD and NTDPC