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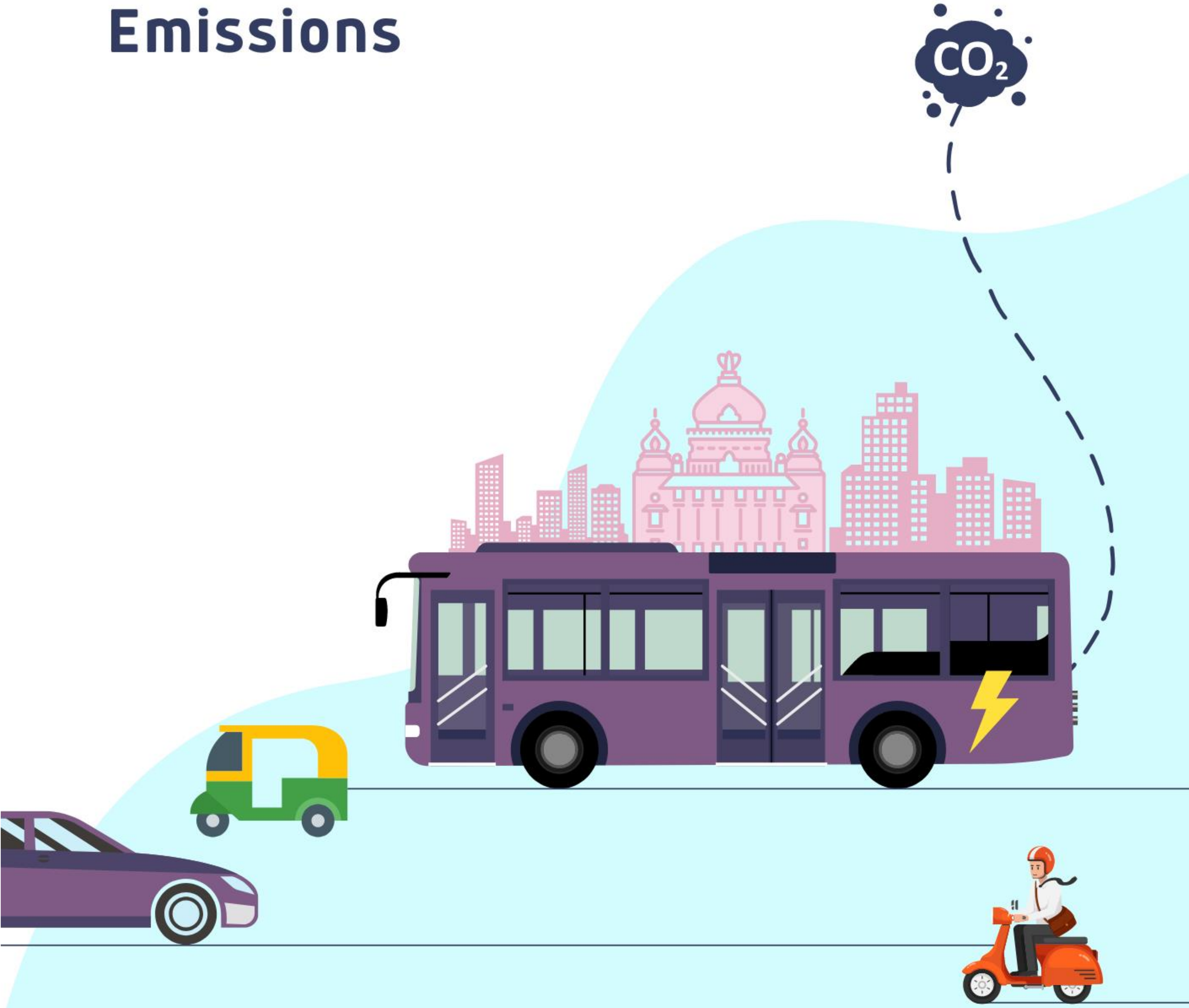
Bengaluru 2030
Impact of EVs on Vehicular Emissions



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Bengaluru 2030: Impact of EVs on Vehicular Emissions

Center for Study of Science, Technology and Policy

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Designed and Edited by CSTEP

Disclaimer

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Bengaluru

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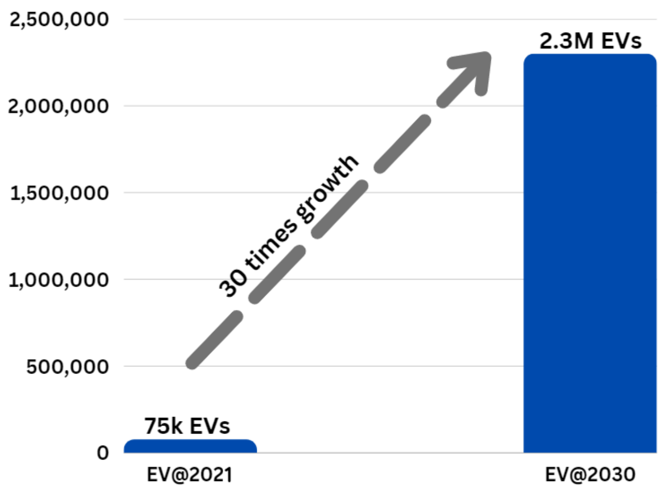
05
POLICE
BENGALURU

Executive Summary

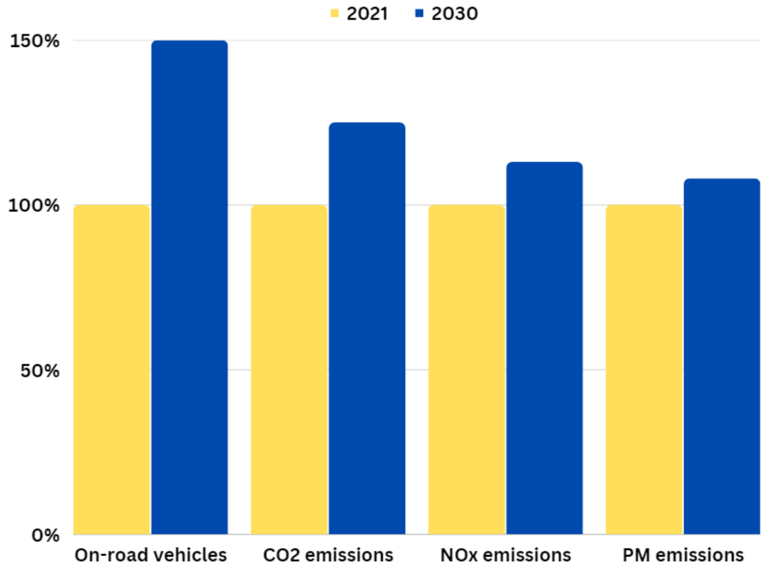
Greenhouse gas (GHG) emissions are a direct cause of human-induced climate change. India accounted for 2.9 billion tonnes of CO_2 emissions in 2019. The transportation sector accounts for roughly 10% or 290 million tonnes of CO_2 emissions per year. Road transport, mainly comprising heavy vehicles (buses and trucks) and to some extent personal vehicles (two wheelers [2Ws] and four wheelers [4Ws]), is the leading contributor to these emissions. Based on the latest trends, a recent study by the Center for Study of Science, Technology and Policy (CSTEP) reported that vehicle electrification is the most practical approach to curb vehicular GHG emissions, with the added benefit of significantly inhibiting sources of urban pollution including particulate matter (PM), nitrogen oxides (NO_x), and black carbon (BC).

In the current study, the on-road vehicle stock in Bengaluru was obtained by accounting for all vehicles registered in the last 20 years (2001–2021) and those that were retired (due to wear and tear, accident, or total loss) during this period. Further, the vehicle population was projected into the horizon year (2030) by extending the past growth trends in each vehicle class. These projections showed that the on-road vehicle stock grows 1.5 times (from 5.7M vehicles to 8.9M vehicles), at an overall growth rate of 5%.



During the same period, a significant uptake of electric vehicles (EVs) was estimated, with sales penetration reaching 100% for most of the vehicle classes, except passenger vehicles. To realise this scenario, the EV segment in Bengaluru needs to grow at a weighted CAGR of 56%. The Indian Energy Storage Alliance projected the EV growth for India to be around 44%; therefore, the current projections seem plausible for a Tier 1 city like Bengaluru. This study estimates an EV fleet size of 2.34M vehicles in 2030, with EVs constituting a sizable proportion of the total on-road vehicles for most classes (35% of 2Ws, 60% of three wheelers, 30% of light goods vehicles, and 28% of buses).

Interestingly, although the vehicle population grows by 1.5 times, vehicular GHG emissions were found to increase only by ~1.25 times, from 11.1M tonnes of CO_2 to 13.8M tonnes of CO_2. This can be directly attributed to the estimated 2.34M EVs with zero tailpipe emissions; this is equivalent to taking 4.85M conventional 2Ws off the roads in Bengaluru. In addition, the projected EV fleet will significantly limit the emissions of NO_x, PM with a diameter of 2.5 µm or less ($PM_{2.5}$), and PM with a diameter of 10 µm or less (PM_{10}), which only increase by 8%–13%, despite the growth in the total vehicular fleet by 1.5 times during 2021–2030.



Finally, the energy requirement to charge the projected EV fleet was determined based on the daily distance travelled by each of the vehicle classes. Approximately, 6.2M units of electricity will be needed to charge the projected 2.34M EVs on a daily basis. In the current energy mix of the Bangalore Electricity Supply Company, 55% of the energy is sourced from thermal power plants. However, for a completely green transition, majority of this electricity should be sourced from a combination of renewable resources available in Karnataka, such as solar, wind, biomass, and hydro. For instance, 1.37 GW of rooftop solar installations, covering a total rooftop area of 16.4 sq km, will be sufficient to fulfil the charging needs of the projected EV fleet. This is an achievable target, considering the city's rooftop solar potential of 3.2 GW.

Overall, there is significant potential for the city of Bengaluru to move towards sustainable mobility solutions. While electric vehicles are inherently more sustainable than conventional fossil fuel-powered vehicles, by ensuring that the majority of the electricity for EV charging is also sourced from non-polluting and renewable sources, we can envisage a future wherein the mobility sector has minimal impact on the environment.

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Abbreviations

2W	Two wheeler
3W	Three wheeler
4W	Four wheeler
AKT	Annual kilometres travelled
BESCOM	Bangalore Electricity Supply Company
BMTC	Bengaluru Metropolitan Transport Corporation
CAGR	Compound annual growth rate
EV	Electric vehicle
GHG	Greenhouse gases
GW	Gigawatt
ICE	Internal combustion engine
IEA	International Energy Agency
IT	Information technology
kW	Kilowatt
kWh	Kilowatt hour
LGV	Light goods vehicle
MW	Megawatt
NITI	National Institution for Transforming India
NO_x	Nitrogen oxides
PM_{10}	Particulate matter with a diameter of 10 µm or less
$PM_{2.5}$	Particulate matter with a diameter of 2.5 µm or less
PV	Photovoltaic
PVA	Photovoltaic available roof area
RTO	Regional Transport Office
RTPV	Rooftop photovoltaic
TCO	Total cost of ownership

1. Background

The mobility segment contributes significantly to greenhouse gas (GHG) emissions. Based on International Energy Agency (IEA) estimates, it makes up roughly 16% of the energy-related emissions in India. Conventionally, vehicle registration data are used for estimating the fleet size of on-road vehicles (CSTEP, 2022) to estimate tailpipe emissions from this sector. The same approach was used to model and estimate pollution levels/CO_2 emissions in previous studies for the city of Bengaluru (Harish, 2012; Wang et al., 2017). However, the actual number of vehicles on the road is significantly lower than the estimated values, since vehicles retire due to various causes such as age, total loss, or accident. Pandey and Venkataraman (2014) developed a novel method for modelling the survival rates of different vehicle classes and used the technique to estimate the on-road vehicle fleet for India. The same approach has been employed in this study for Bengaluru.

To reduce emissions from the mobility sector, transitioning the current internal combustion engine (ICE) fleet to an electric one could be the path forward. Currently, several indigenous and foreign automobile manufacturers are offering electric vehicle (EV) alternatives in the Indian market. In addition, other players in the Indian automobile sector are in the process of partially or completely switching to EVs in the short-to-near term.

However, despite the evident benefits of electrifying the vehicular fleet, there are many hurdles preventing mass adoption. Some of these are listed below:

- In case of most vehicle classes (such as cars, motorbikes, and buses), EVs are significantly more expensive than ICE vehicles.
- The Indian public EV charging infrastructure is still in its infancy and requires rapid scaling up.
- Because the cost of batteries constitutes ~40% of the overall cost of EVs, manufacturers are forced to install smaller batteries to lower the price of the vehicle. This, in turn, leads to shorter-range vehicles, exacerbating range anxiety among EV owners.
- As the EV sector remains at a nascent stage, various manufacturers follow different standards for charging protocols or cell chemistries. There is an urgent need for standardisation to ensure consumers can experience cross-platform services including fast charging and battery swapping in the future.

In addition to the development of strategies to address the abovementioned hurdles, the real-world implications of transitioning to an electric fleet (including the impact on emissions, effect on the grid, and vehicular congestion) need to be evaluated.

2. Objective of the Study

The study aimed to analyse the effect of vehicle electrification on Bengaluru's GHG emissions and the overall impact on the electrical grid managed by the Bangalore Electricity Supply Company (BESCOM).

The following were the main objectives of the study:

- Fleet size: To estimate the current GHG emissions, the size and composition of Bengaluru's vehicular fleet during the base year 2021 were determined.
- Fleet projection: The growth pattern of the fleet and its projected composition were assessed during the horizon year 2030.
- EV composition: Because each vehicle class has different charging requirements and use cases, both the current and projected composition of the EV fleet were evaluated.
- Emissions: This study focussed only on tailpipe (downstream) emissions from Bengaluru's vehicular fleet.
- Energy requirement: Based on the size of the fleet, the total amount of electricity needed to charge the fleet on a daily basis was calculated.
- Solar integration: Finally, based on the EV fleet's energy requirements, the quantum of rooftop photovoltaic (RTPV) systems needed to offset the energy required for charging was calculated.

3. Limitations of the Study

- The study relied on data sourced from the Vahan database of the State Transport Department. This is a database of annual vehicle registrations dated back to 2013, and being the only source available, it cannot be validated against another source for accuracy.
- For this study, only vehicles registered within Bengaluru were considered. Although in the real world, many vehicles registered within Bengaluru might be plying out of the city, while many vehicles registered outside the city might be plying within it. These two categories of vehicles were assumed to cancel each other out on a net basis.
- Because the focus of this study was to analyse the impact of electrification on Bengaluru's GHG emissions, only those classes of vehicles with EV alternatives available in the Indian market were considered. However, heavy freight is one segment that has no clear pathway for electrification (fuel cells, strong hybrid, battery electric, pantograph etc.) as of now. Therefore, emissions from this category were not considered in this study.
- This study accounted for vehicles being retired every year. To accomplish this, a survival rate model developed using average ownership rates across India was used. However, vehicle ownership trends differ between Tier-1 cities like Bengaluru and the rest of India (Tier-2 and Tier-3 cities, towns, and villages). Despite this, the same model was employed for Bengaluru in this study because similar city-level models were unavailable.

4. Area of Study

Bengaluru is one of the leading Tier-1 metropolitan cities in India across many metrics. The city accounts for more than a third of Karnataka's gross state domestic product and has one of the highest vehicle ownership rates in the country. Being the IT capital of India, Bengaluru has witnessed a significant influx of migrant workers from across the country over the last few decades. As a result, the city's population has burgeoned to more than 12 million and is projected to grow to 20 million by 2030 (Infrastructure Development Corporation [Karnataka] Limited, 2019).

The study region included the entirety of the Bengaluru Metropolitan Area, spanning 1,300 sq km. Vehicles registered within this region were considered for this study. Further, the city has a mix of public and private transport options. The public transport system is primarily dominated by the city's thriving population of buses managed by the Bengaluru Metropolitan Transport Corporation (BMTC) and private bus operators. As per the Comprehensive Mobility Plan for Bengaluru (2019), 56% passengers in the city use buses for daily commute. In addition to a robust bus network, the city has a nascent metro system colloquially termed 'Namma Metro', which is managed by the Bengaluru Metropolitan Rail Corporation Limited. As of May 2022, the metro-rail network reached a daily ridership of more than 4.5 lakhs. The evolving network has two metro lines (green and purple), spanning 55 km of track length with 52 stations. In terms of private vehicle ownership, 84% of households own motor vehicles, with two wheelers (2Ws) constituting more than two thirds of the total registered vehicles. Four wheelers (4Ws) are the second most populous category of vehicles plying the city roads.

In terms of emissions, the transportation sector accounts for 68% of particulate matter with a diameter of 10 µm or less (PM_{10}) and 60% of nitrogen oxide (NO_x) emissions (CSTEP, 2022). In particular, diesel vehicles are major contributors to emissions of PM_{10} (89 $\mu g/m^3$) and particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$; 41$\mu g/m^3$) in Bengaluru.

5. Data Sources for the Study

The primary source of all data used in this study was the Vahan database of the Ministry for Road Transport and Highways. This database contains monthly vehicle registrations across all vehicle classes reported by the regional transport offices (RTO) throughout the country. Data were collected from the following RTOs in the study area:

- Bengaluru Central
- Bengaluru East
- Bengaluru West
- Bengaluru North
- Bengaluru South
- KR Puram
- Jananabharathi
- Yelahanka
- Electronic City
- Devanahalli
- Chandapura

The data collected were used to record annual registrations across the following vehicle classes in the study region:

- Heavy vehicles (passenger and goods)
- Medium vehicles (passenger and goods)
- Light vehicles (passenger and goods)
- Three wheelers (3Ws)
- 2Ws

6. On-road Fleet (2021)

One of the challenges of this study was that the Vahan database contains information dated back to 2013. Another challenge regarding most data sources on vehicle registrations is that they report the total number of vehicles registered since the beginning of record collection. For example, the Monthwise Vehicle Statistics Report published by the Karnataka Transport Department (2021) reported the number of 2Ws in the study region to be 65,85,035 as of December 2020. This is an exaggeration of the actual figures since the data do not account for vehicles retiring every year. This study employed an approach similar to that used by Pandey and Venkataraman (2014) to account for the declining vehicle fleet in Bengaluru over the years, using survival rates for different classes.

The survival rate (S_r) of vehicles registered each year is a key parameter and a function of the age (a) of a vehicle, as presented below:

$$S_r = \frac{1}{1+e^{\left[\alpha\left(1-\frac{a}{L_{50}}\right)\right]}}, \qquad (1)$$

where α and L_{50} are vehicle class-specific parameters. L_{50} represents the average age at which half the vehicle fleet retires, and a is the age of the vehicle. The survival rate is used to derive the survival fraction, which is denoted as the ratio of the survival rate at age a to the survival rate at age 0.

The survival fraction is a function used to account for the declining stock of vehicles every year. As shown in Fig. 1, the survival fraction of most vehicle classes aged above 20 years declines to 0, except for 4Ws, which last an additional 10+ years before retiring.

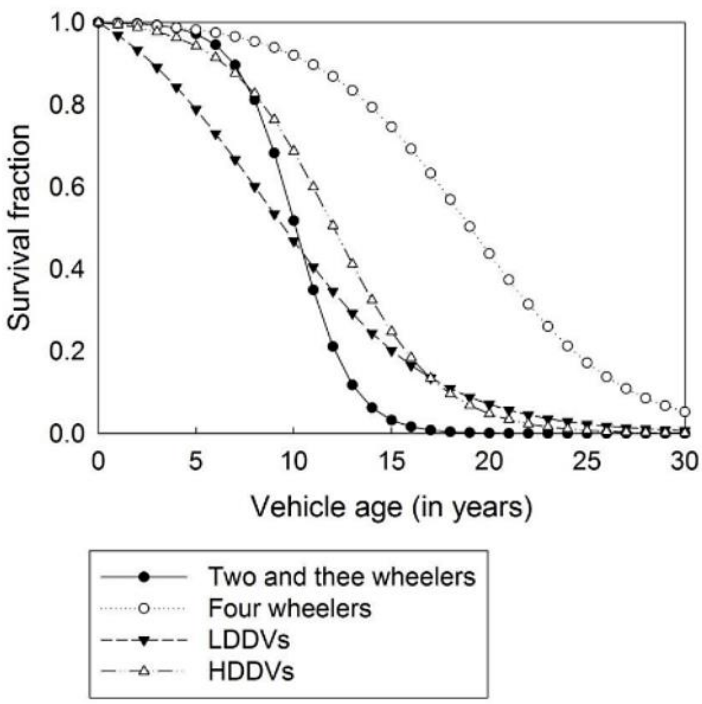


Figure 1: Survival fraction of different classes of registered vehicles in India (Source: Pandey & Venkataraman, 2014). LDDV: light-duty diesel vehicles; HDDV, heavy-duty diesel vehicles.

The survival fractions were then used to calculate the surviving vehicle stock during the base year using the following equation:

$$V_{c,a} = \sum_{t=0}^{t=a} V_{c,a}(t-a) * S_{f,c,a}, \quad (2)$$

where $V_{c,a}$ is the surviving stock for vehicle class c of age a during the base year, $V_{c,a}$(t-a) is the number of new registrations of vehicle class c at age a, and $S_{f,c,a}$ is the fraction of vehicle class c at age a.

However, because only new registration data going back to 2013 were obtained, consolidated data from the Road Transport Year Book (Transport Research Wing, Ministry of Road Transport and Highways, Government of India, 2012) dated back to 2002 were used. Thus, the required data spanning 20 years were collected to effectively calculate the size of the surviving fleet for most vehicle classes (Fig. 2). Here, it was assumed that only half the fleet of 4Ws registered prior to 2002 survived as of 2022.

Considering only consolidated data on new vehicle registrations from 2002 to 2012 were obtained, it was assumed that the individual class composition was the same as that observed from 2013 to 2021, for which the actual data were obtained from the Vahan database (Table 1).

Table No. 1.3

Total Registered Motor Vehicles In Million Plus Cities
(as on 31st March)

(In thousands)

Million Plus Cities	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1	2	3	4	5	6	7	8	9	10	11	12
Agra	...	...	...	...	...	...	...	...	580	640	704
Ahmedabad	899	978	1,075	1,632	1,780	1,451	1,586	1,691	...	...	1,682
Allahabad	...	...	...	...	...	...	...	...	...	...	738
Amritsar		...	...	...	...	...	...	...	...	...	803
Aurangabad	...	...	...	...	...	...	...	...	...	253	281
Bengaluru	1,680	1,771	1,891	2,232	2,617	2,179	2,640	3,016	3,491	3,791	4,156

Figure 2: Total registered motor vehicles during 2002–2012 (Source: Road Transport Year Book 2011–12)

Table 1: Class-wise composition of new vehicle registrations (2013–2021)

Vehicle class	Composition of new vehicle registrations
Two wheelers	**71.6%**
Three wheelers	**2.6%**
Four wheelers (cars and taxis)	**22.7%**
Four wheelers (light goods vehicles)	**1.7%**
Buses	**0.2%**
Trucks and lorries	**1.2%**

Considering all factors mentioned above, the distribution of the surviving vehicle stock plying within the study region is presented in Fig. 3. In total, 5.7M surviving vehicles were noted, as opposed to the estimate of 10M without accounting for vehicles retiring annually.

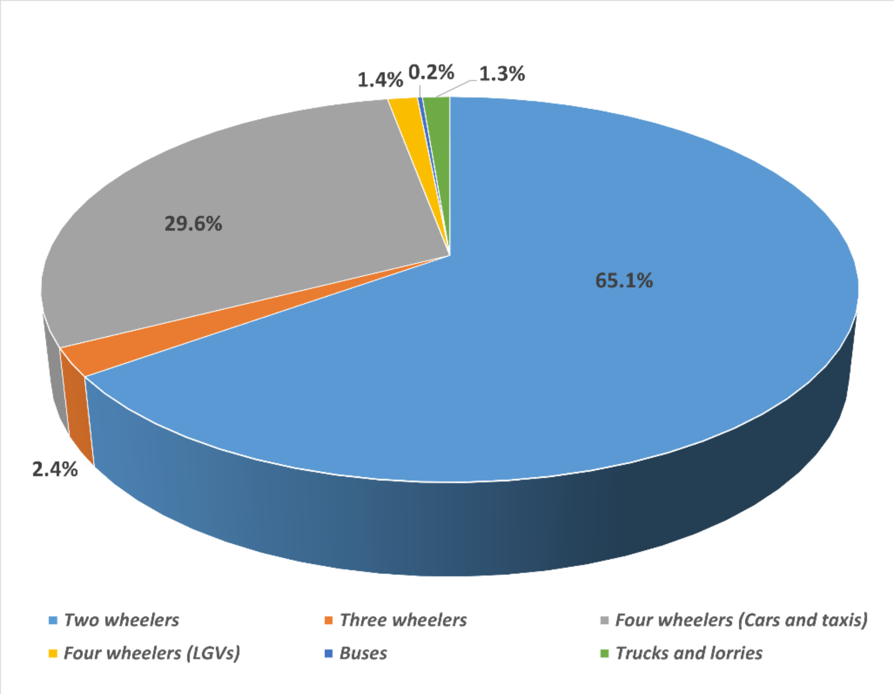


Figure 3: Class-wise composition of Bengaluru's on-road vehicle fleet (as of December 2021). LGV, Light goods vehicle.

7. Tailpipe Emissions (2021)

The fleet average annual kilometres travelled (AKT) for each vehicle class (Peshin et al., 2022) were calculated. Notably, the current study did not account for emissions originating from trucks and lorries because a pathway to electrification for this particular class has not been reported so far. Thus, the emission data covered the five remaining classes during both the base year (2021) and horizon year (2030). The values shown in Table 2 were used for calculations pertinent to both the base year and horizon year.

Table 2: Fleet annual kilometres travelled for different vehicle classes in Bengaluru

Vehicle class	Daily distance (km)	Annual distance travelled (km)
Two wheelers	40	**14,600**
Three wheelers	120	**42,000**
Four wheelers (cars and taxis)	45	**16,425**
Four wheelers (light goods vehicles)	100	**35,000**
Buses	200	**70,000**

Next, the emission factors of different classes were calculated based on vehicle mileages and volumetric CO_2 emissions per litre of fuel combusted (Table 3). Emission factor is a function of a vehicle's mileage and volumetric emissions and can be calculated using the following equation:

$$\varepsilon_c = \frac{\mu_c}{m_c}, \quad (3)$$

where ε_c is the class-specific emission factor, m_c is the average fleet mileage of a vehicle class, and μ_c is the class-specific volumetric emission rate. The values for m_c and μ_c were obtained from the report published by Peshin et al. (2022).

Table 3: Emission factors for different vehicle classes

Vehicle class	Average fleet mileage (km/L)	Volumetric emissions (g CO_2/L)	Emission factor (g CO_2/km)
Two wheelers	48.8	2,272	**47**
Three wheelers	21.5	2,692	**125**
Four wheelers (cars and taxis)	10.1	2,272	**225**
Four wheelers (light goods vehicles)	8.6	2,644	**307**
Buses	3.5	2,644	**755**

Further, the data from Tables 2 and 3 were used to calculate fleet-specific annual emissions for each class using the following equation:

$$E_c = n_c \times AKT_c \times \varepsilon_c \quad , \quad (4)$$

where n_c represents the total stock of vehicles of class c plying within the study region.

Based on Equation 4, the fleet-wide emissions for the city are reported in Table 4 below.

Table 4: Fleet-wide emissions in Bengaluru as of December 2021

Vehicle class	Emissions per vehicle (tonnes CO_2/year)	Number of vehicles plying on road	Fleet-wide emissions (million tonnes CO_2/year)
Two wheelers	0.68	37,23,810	**2.53**
Three wheelers	5.26	1,35,796	**0.71**
Four wheelers (cars and taxis)	3.69	16,94,166	**6.30**
Four wheelers (light goods vehicles)	10.76	79,896	**0.86**
Buses	52.88	13,370	**0.71**

Of note, emissions originating from trucks and lorries were not considered because this study focused on pathways to fleet electrification and there is no clear pathway for electrification for the heavy goods vehicles class as of now, even though fleet emissions from this class are considerably high (3.54M tonnes CO_2/year).

Fig. 4 presents the distribution of class-wise emissions. As evident from the figure, 4Ws account for the largest share of emissions, followed by 2Ws and 4Ws (light goods vehicles [LGVs]), whereas 3Ws and buses have similar emission shares.

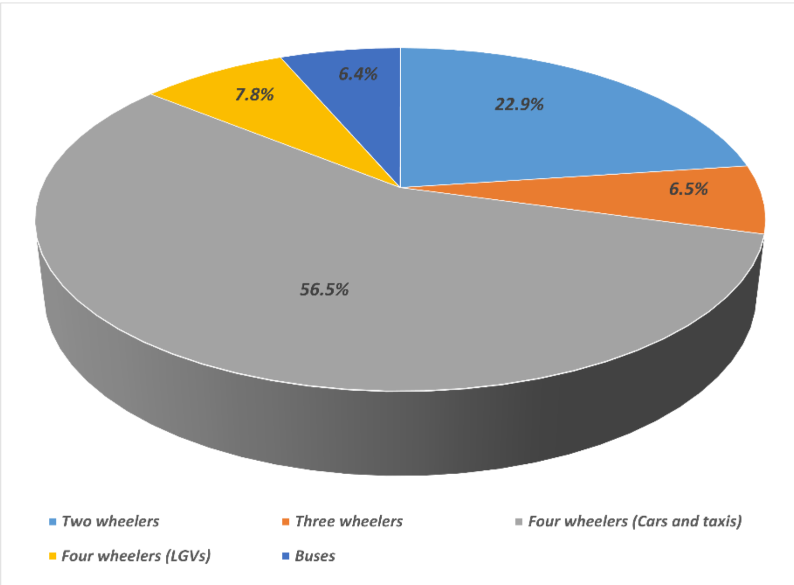


Figure 4: Vehicle class-wise emissions from Bengaluru's on-road fleet (as of December 2021). LGV, Light goods vehicle.

Similarly, the pollution load for the vehicular fleet in 2021 was calculated for the three most prominent pollutants: NO_x, $PM_{2.5}$, and PM_{10}.

The approach used in this study was similar to that utilised in the report by CSTEP (2022), wherein the number of on-road vehicles (based on survival rates) and emission factors for each pollutant class were used to calculate tailpipe emissions. The following equation was used to calculate the emission loads for each vehicle class:

$$E_c = AKT_c * n_c * \omega_c, \quad (5)$$

where E_c is the fleet-wide emission, n_c is the fleet strength, and ω_c is the emission factor for each of the three pollutant classes.

The emission factors (in g/km) shown in Table 5 were used for this analysis (CSTEP, 2022).

Table 5: Vehicular pollutant emission factors (g/km)

Vehicle age	Pollutant	2W	3W	4W (P)	4W (C)	Bus
0–5 years	NO_x	0.25	0.19	0.09	2.12	9.3
	$PM_{2.5}$	0.117	0.135	0.0018	0.4275	0.378
	PM_{10}	0.013	0.015	0.002	0.475	0.42
5–10 years	NO_x	0.27	0.19	0.21	2.3	11.57
	$PM_{2.5}$	0.0225	0.0135	0.0054	0.5085	2.8845
	PM_{10}	0.025	0.015	0.006	0.565	3.205
10–15+ years	NO_x	0.27	0.19	0.65	2.3	11.57
	$PM_{2.5}$	0.0225	0.0135	0.0054	0.5085	2.8845
	PM_{10}	0.025	0.015	0.006	0.565	3.205

2W: Two wheelers; 3W: Three wheelers; 4W (P): Four wheelers (personal); 4W (C): Four wheelers (commercial); NO_x: Nitrogen oxides; PM_{10}: Particulate matter with a diameter of 10 μm or less; $PM_{2.5}$: Particulate matter with a diameter of 2.5 μm or less

As shown in Table 5, pollutant emission factors vary by the age of a vehicle and across vehicle classes. In addition to the total size of the on-road vehicular fleet at the end of 2021 (Section 6), the survival rates were analysed and the age-wise composition of vehicles were determined (Table 6).

Table 6: Vehicle age-wise composition

Vehicle age	2W	3W	4W (P)	4W (L)	Bus
0–5 years	48%	48%	35%	50%	42%
5–10 years	37%	37%	34%	36%	38%
10–15+ years	15%	15%	32%	14%	20%

2W: Two wheelers; 3W: Three wheelers; 4W (P): Four wheelers (personal); 4W (C): Four wheelers (commercial).

Next, the pollution loads for each of the vehicle classes in 2021 were calculated. The results are shown in Table 7.

Table 7: Cumulative vehicular pollution loads in 2021

Pollutant	2W	3W	4W (P)	4W (L)	Bus	TOTAL
NO_x (tonnes/year)	14,162.5	1,083.7	8,571.1	6,181.6	9,928.8	**39,928**
$PM_{2.5}$ (tonnes/year)	944.2	77	115.5	1,309.5	1,706.2	**4,152**
PM_{10} (tonnes/year)	1,049.2	85.6	128.3	1,455	1,895.8	**4,614**

2W: Two wheelers; 3W: Three wheelers; 4W (P): Four wheelers (personal); 4W (C): Four wheelers (commercial); NO_x: Nitrogen oxides; PM_{10}: Particulate matter with a diameter of 10 µm or less; $PM_{2.5}$: Particulate matter with a diameter of 2.5 µm or less

As shown in Table 7, 2Ws and buses were the major contributors of NOx emissions, whereas 4Ws and buses were the primary contributors of PM_{10} and $PM_{2.5}$ emissions. It should be noted that similar to the CO_2 emissions calculation, this study did not account for the pollution load of trucks and lorries because there is no pathway for electrification for this class.

8. Fleet Projection (2030)

To project the emissions into the horizon year (2030), the size of the fleet during the horizon year was calculated. For this, past growth rates of new vehicle registrations across all vehicle classes of interest were considered. The Vahan database was used to source these data. The class-wise growth figures are provided in Table 8.

Table 8: Compound annual growth rate (CAGR) of different vehicle classes in Bengaluru

Vehicle class	CAGR during 2013–2021
Two wheelers	10.2%
Three wheelers	10.2%
Four wheelers (cars and taxis)	7.1%
Four wheelers (light goods vehicles)	11.0%
Buses	8.7%
Trucks and lorries	8.7%

Using these growth figures, the total vehicle stock on Bengaluru roads was projected for 2030. In addition, this study accounted for vehicles that would have been retired between 2021 and 2030. Fig. 5 shows the projected fleet size of 8.9M vehicles and the fleet composition.

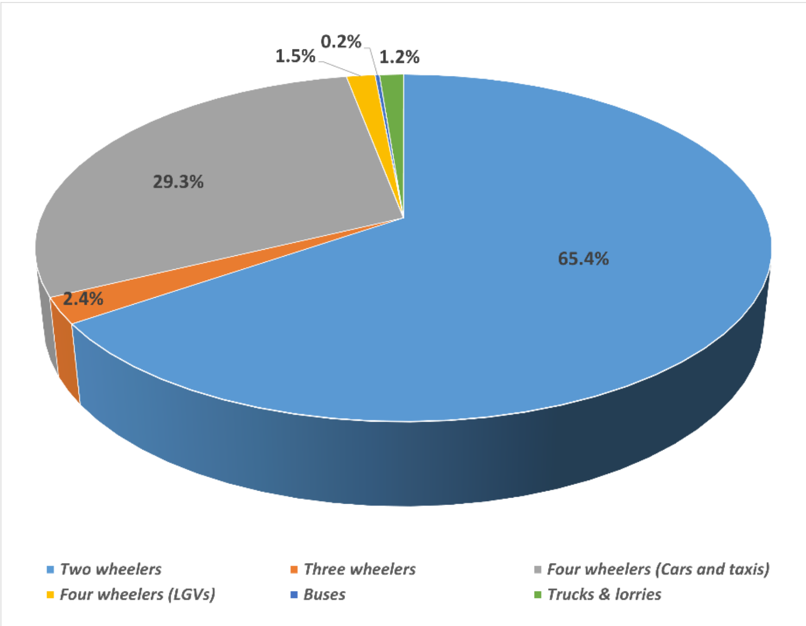


Figure 5: Composition of Bengaluru's projected vehicle fleet in 2030. LGV, Light goods vehicle.

The fleet strength was projected to increase 1.6 times over the 9-year period, from 5.7M vehicles in 2021 to about 8.9M in 2030. The fleet composition was found to remain more or less unchanged, with a slight decrease in the share of 4Ws between the base and horizon years.

As of December 2021, the registered EV fleet in Bengaluru was roughly 75,000 vehicles. The fleet composition is shown in Table 9. Electric 3Ws accounted for over 10% of the total registered 3W stock, whereas the other EV classes showed very low penetration. This could be because 3Ws are primarily used commercially, and as electric 3Ws have a lower total cost of ownership (TCO) than their ICE counterparts, fleet managers are proactively switching to electrification (Mishra, 2022).

Table 9: Bengaluru's electric vehicle (EV) fleet composition as of 2021

Vehicle class	Registered EVs (2021)	EV stock (percentage of the total stock)
Electric two wheelers	51,166	1.37%
Electric three wheelers	15,729	11.58%
Electric four wheelers (cars and taxis)	8,685	0.51%
Electric four wheelers (light goods vehicles)	114	0.14%
Electric buses	94	0.70%
TOTAL	75,788	-

Although this study projects the total fleet size during the horizon year, the share of EVs in the total fleet remains unclear. To determine this, a study by the National Institution for Transforming India (NITI) Aayog (2021) estimated the potential sales penetration rates of EVs in each vehicle class by 2030 (Table 10).

Table 10: NITI Aayog-projected electric vehicle (EV) sales penetration in Bengaluru in 2030

Vehicle class	EV sales penetration
Electric two wheelers	30%
Electric three wheelers	70%
Electric four wheelers (personal cars)	15%
Electric four wheelers (taxis and light goods vehicles)	30%
Electric buses	-

Few observations based on the NITI Aayog projections are given below:

- It assumes a very low sales penetration of 2Ws and 3Ws in 2030, although indigenous EV technology in these two segments is exponentially scaling and improving.
- Regarding electric 4Ws, the study assumes a 15% penetration rate for personal cars and 30% for commercial ones (taxis and LGVs). The personal car segment might witness tepid growth due to the prevailing higher cost of EV alternatives than that of ICE vehicles. However, the commercial segment should witness fairly high growth because fleet owners have been proactively switching to electrification, e.g. in case of electric 3Ws (Mishra, 2022).
- The study does not consider buses in its ambit; however, this vehicle segment has a 100% EV sales penetration potential by 2030. This is because majority of the buses are owned by BMTC, and being a government body, they can be pushed towards complete electrification.

- Finally, the study does not account for the extremely high fuel prices that act as a natural push towards electrification, as a result of the low running costs (INR/km) of EVs.

However, to have a very high EV sales penetration rate across most classes of vehicles, the TCO needs to decrease significantly from the current levels. As the battery pack is a major contributor to the cost of manufacturing an EV, accounting for more than 30% of the overall costs, a significant reduction in battery prices should spur EV adoption (König et al., 2021). Economies of scale, newer and cheaper chemistries, and innovative business models should help overcome these challenges in the future.

9. Emissions Projection (2030)

Instead of adopting ad hoc sales penetration rates in the horizon year, the emissions based on the class-wise percentage of EVs in the total on-road stock were estimated. This is a better approach for setting targets because the numbers can be tracked from annual vehicle registration data and stakeholders can adjust policies in real time to meet the targets set for the horizon year.

Table 11 shows the projected composition of the EV fleet within the overall fleet in 2030. These values represent an aggressive EV adoption scenario for Bengaluru, and to meet these targets, all vehicle classes, except personal cars (20%), would experience a 100% sales penetration rate in 2030. The overall emission scenario for this projection is described in Fig. 6.

Table 11: Projected electric vehicle (EV) composition in the overall fleet in 2030

Vehicle class	EV fleet composition
Electric two wheelers	35%
Electric three wheelers	60%
Electric four wheelers (cars and taxis)	5.5%
Electric four wheelers (light goods vehicles)	30%
Electric buses	28%

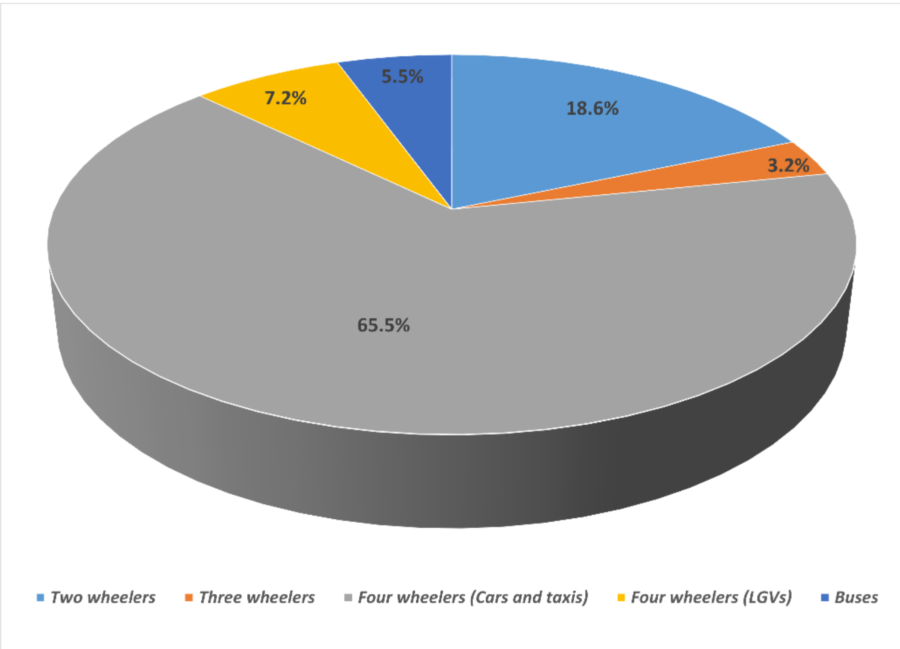


Figure 6: Vehicle class-wise emissions from Bengaluru's projected fleet in 2030. LGV, Light goods vehicle.

Among all classes of vehicles plying on Bengaluru roads in 2030, 4Ws are projected to be the largest contributors to vehicular emissions. Further, 2Ws account for less than 1/5th of the emissions, with 4Ws (LGVs), 3Ws, and buses together contributing roughly 15% of the projected emissions. Emissions from trucks and lorries have not been included here (5.3M tonnes of CO_2/year) because there is no clear pathway for electrification for this vehicle class as of now.

From the above analysis, it is evident that even as the total stock of vehicles on Bengaluru roads is projected to increase significantly from 5.7M to 8.9M vehicles (more than 150%), emissions would only increase by a small margin (from 11.1M tonnes CO_2/year to 13.8M tonnes CO_2/year, i.e. by less than 125%). This is because a large portion of the fleet is expected to have been electrified by then.

In addition, the cumulative pollutant emissions for the projected fleet were calculated using a similar approach as that used in Section 7. The resulting fleet-wide emissions are given in Table 12.

Table 12: Cumulative vehicular pollution loads in 2030

Pollutant	2W	3W	4W (P)	4W (L)	Bus	TOTAL
NO_x (tonnes/year)	14,358.5	675.3	12,403.2	7,160.6	10,648.5	**45,246**
$PM_{2.5}$ (tonnes/year)	957.3	48	167.1	1,516.8	1,829.9	**4,519**
PM_{10} (tonnes/year)	1,063.6	53.3	185.6	1,685.4	2,033.2	**5,021**

2W: Two wheelers; 3W: Three wheelers; 4W (P): Four wheelers (personal); 4W (C): Four wheelers (commercial); NO_x: Nitrogen oxides; PM_{10}: Particulate matter with a diameter of 10 μm or less; $PM_{2.5}$: Particulate matter with a diameter of 2.5 μm or less

Thus, as a result of switching to EVs, emissions of roughly 3.3M tonnes of CO_2/year could be avoided. This is akin to taking 4.85M ICE 2Ws off the roads in Bengaluru by 2030. To realise this scenario, a high growth in each of the EV classes is required, as shown in Fig. 7 below.

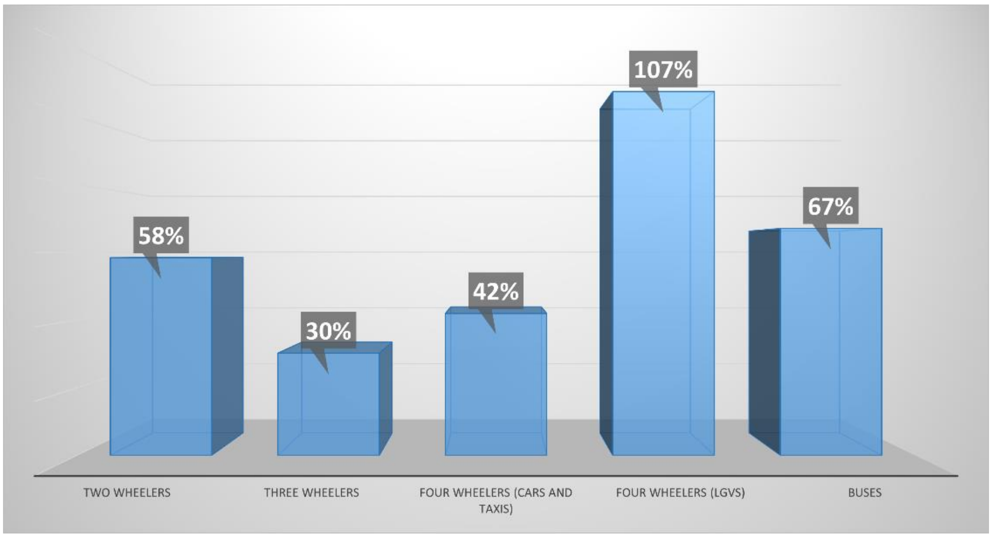


Figure 7: Required CAGR across vehicle classes to meet EV fleet targets in 2030. CAGR, compound annual growth rate; EV, electric vehicle; LGV, Light goods vehicle.

Although these growth figures might seem abnormally high, according to the India Energy Storage Alliance (2022), the EV market is projected to grow at a compound annual growth rate (CAGR) of **44%** (during 2020–2027), whereas the weighted average CAGR across all classes in the current scenario is roughly **56%**. Thus, with increased efforts and incentivising, even these extreme projections could be realised by 2030.

10. Energy Requirement of the Projected EV Fleet

To calculate the electricity consumption of the projected EV fleet, the composition of the fleet and certain vehicle parameters for representative EVs in the fleet were analysed (Table 13).

Table 13: Projected electric vehicle (EV) fleet characteristics

Vehicle class	Fleet composition	EV battery pack size (kWh)	EV range (km/full charge)
Electric two wheelers	20,22,146	6	200
Electric three wheelers	1,29,293	9	150
Electric four wheelers (cars and taxis)	1,41,390	60	400
Electric four wheelers (light goods vehicles)	38,928	30	250
Electric buses	5,672	500	400
TOTAL	**23,37,429**	-	-

Battery pack sizes and EV ranges were obtained based on projections from a previous working paper on EV battery sizes in India during 2020–2035 (Godel et al., 2021). Evidently, electric 2Ws have the smallest batteries and electric buses have the largest. Next, the daily commute behaviour of each vehicle class was used to determine the electricity requirement of the entire fleet. Here, the same drive patterns as those used in the emissions calculations for ICE vehicles were used, and the assumptions are listed in Table 14 below.

Table 14: Daily energy consumption of electric vehicle (EV) fleet

Vehicle class	Daily commute (km/day)	Charge requirement (kWh/day)	EV fleet energy consumption (MWh/day)
Electric two wheelers	40	1.2	2,427
Electric three wheelers	120	7.2	931
Electric four wheelers (cars and taxis)	45	6.8	954
Electric four wheelers (light goods vehicles)	100	12	467
Electric buses	200	250	1,418
TOTAL	-	-	**6,200**

As shown in Table 14, 6.2M units of electricity will be needed to charge the entire EV fleet on a daily basis in 2030. With planned capacity upgrades to BESCOM's generation assets, this additional energy requirement could be easily fulfilled.

Another point to consider here is the impact on the grid's peak demand once the EV fleet is availing charging services. This is a complex scenario to model, as it depends on various factors, including the following:

- Availability of fast-charging solutions
- Charging period (overnight, daytime, early morning, late evening, etc.)
- Charging frequency
- Time of day tariffs by BESCOM

Further, BESCOM's load curve (dated 7 July 2022) was evaluated and a synthetically generated load profile based on typical EV charging patterns for different vehicle classes was used. Fig. 8 presents a plot comparing the additional power demand from EVs in 2030 with BESCOM's current demand. This is merely a representational scenario of the impact on the grid once a significant number of EVs become operational, and the actual impact might be completely different.

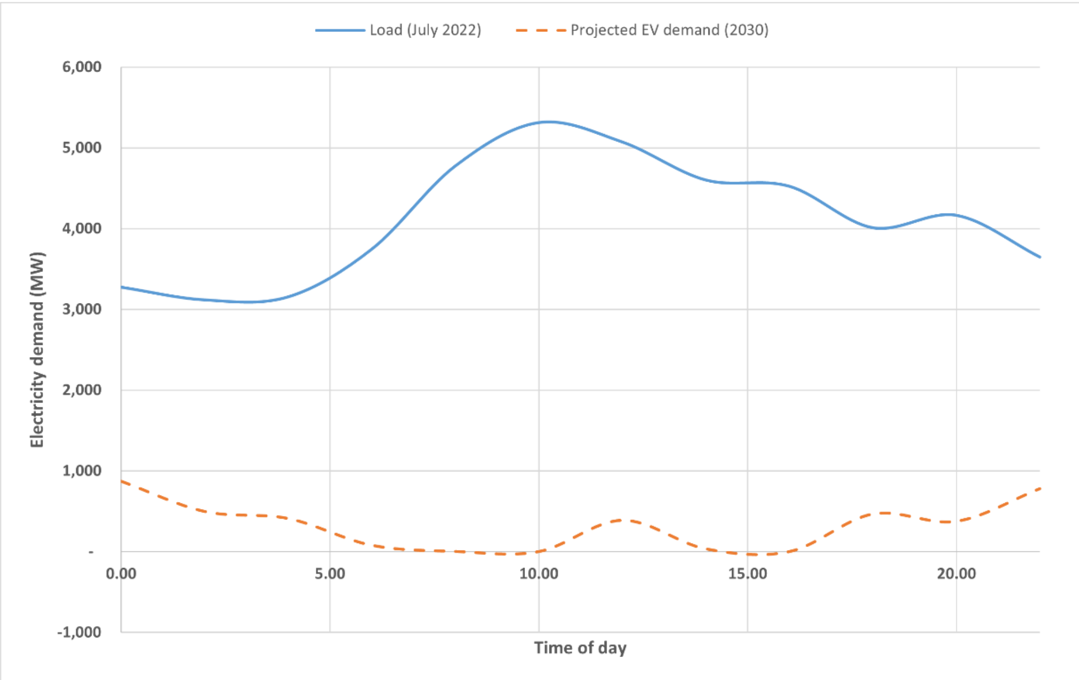


Figure 8: BESCOM load curve (July 2022) and projected EV load profile in 2030. BESCOM, Bangalore Electricity Supply Company; EV, electric vehicle.

11. Green Mobility

This study only considered tailpipe emissions from Bengaluru's vehicle fleet during the base year (2021) and the projections for 2030. However, total emissions include both upstream (e.g. well-to-tank for ICE vehicles) and downstream (e.g. tank-to-wheel or tailpipe for ICE vehicles) emissions. In case of EVs, upstream emissions are attributed to the electricity source for charging. For example, upstream emissions can be significantly higher if the electricity is entirely generated from a grid with only coal-fired power plants instead of a grid with a mix of only solar, wind, and hydro (no net emissions). In fact, during 2022, BESCOM procured ~18,200 million units or 55% of its annual energy demand from thermal power plants and the remaining energy was generated from a mix of solar, wind, biomass, hydro, and nuclear sources.

Ideally, strategies are needed to maximise the overall impact of EVs on GHG emissions compared with that of ICE vehicles. This will enable 'Green Mobility', wherein both upstream and downstream emissions are at a minimum.

Although there are various renewable sources available in the BESCOM energy mix, one of the most practical ways of procuring renewable energy is to offset all the electricity needed by EVs in 2030 with RTPV systems.

An RTPV system is highly modular, ranging from a few kilowatts (kW) to as high as tens of megawatts (MW). For the projected EV fleet, 6,200 MWh of electricity will be required on a daily basis. Therefore, for a 'Green Mobility' transition, all this energy can be offset with a renewable electricity source like RTPV. A typical 1 kW RTPV system produces 1,650 kWh/kW of electricity on an annual basis or roughly 4.5kWh/kW on a daily basis (specific production). Considering the daily electricity requirement for the EV fleet obtained in this study, the following equation can be used to determine the total size of RTPV systems needed for the offset:

$$\text{RTPV size}_{\text{kW}} = \frac{Energy\ required\ by\ the\ EV\ fleet_{kWh/day}}{Specific\ production_{kWh/kW-day}} \quad (6)$$

Using Equation 6, it was determined that 1,370,831 kW (~1.37 GW) of RTPV systems would be required to offset all the energy needed by the projected EV fleet in 2030. Next, the rooftop area required to install these RTPV systems was determined. Previously, a study was conducted to evaluate the RTPV potential of Mumbai (Singh & Banerjee, 2015) using a combination of GIS-based image analysis and PVSyst simulations to determine the photovoltaic available roof area (PVA) ratio. Ideally, PVA ($Sq\text{-}ft_{PV}/Sq\text{-}ft_{total\ rooftop}$), which is the fraction of the total rooftop area that is covered with solar modules, should be as high as possible. However, owing to parameters such as roof orientation, shape, and size; obstacles; and nearby shadows, only a portion of the rooftop is accessible for installing solar modules for an RTPV system.

The study by Singh and Banerjee (2015) focused on Mumbai, and in the current study, the various residential, commercial, industrial, and educational building rooftops in Bengaluru were assumed to have similar parameters. The value of PVA ranges from 0.28 to 0.4 for Mumbai, and PVA of 0.4 for Bengaluru was used in the current study. Therefore, for the required 1.37 GW of RTPV systems, 17,61,80,418 sq ft or 16.38 sq km of rooftop area would be needed to effectively install all solar modules. In 2018, CSTEP conducted a project to develop the CREST tool (version 1.1) to map the entire rooftop landscape for the city of Bengaluru, spanning an area of approximately 1,100 sq km, using LiDAR technology installed on a low flying helicopter. The high-resolution images captured by the LiDAR sensor covered the city's topography, buildings, and trees. Based on the findings, it was determined that the city has a rooftop solar potential of 3.2 GW across the 1.4 lakh buildings that were surveyed. Hence, the estimate of 1.37 GW of rooftop solar required for the 'Green Mobility' transition is an achievable target, given the immense solar resource available in the city.

12. Conclusions and Path Forward

The purpose of this study was to understand the impact of electrification on tailpipe emissions from the millions of vehicles plying on road in Bengaluru. The fleet size during the base year (2021) was estimated, and past growth trends were used to project the fleet size during the horizon year (2030).

To estimate the number of on-road vehicles, most previous studies relied on the transport department's vehicle registration data; however, the current study also accounted for vehicles that are being retired or will retire in the future (for projections). This is a more accurate approach to estimate the on-road vehicle fleet size. The results showed that the **fleet size grows from 5.7M in 2021 to 8.9M in 2030**, at an average growth rate of 5% for all vehicle classes.

The composition of the fleet during the horizon year remains more or less stable compared with that during the base year, with **2Ws constituting ~65% of the fleet**, 4Ws constituting ~30%, and the remaining classes (3Ws, LGVs, and buses) constituting less than 5%. Although the projected number of 2Ws is more than double that of **4Ws,** the **emissions contributed by the latter are more than 3.5 times those contributed by the former**. This can be directly attributed to 4Ws having a significantly higher emission factor than 2Ws (Figs. 9 and 10).

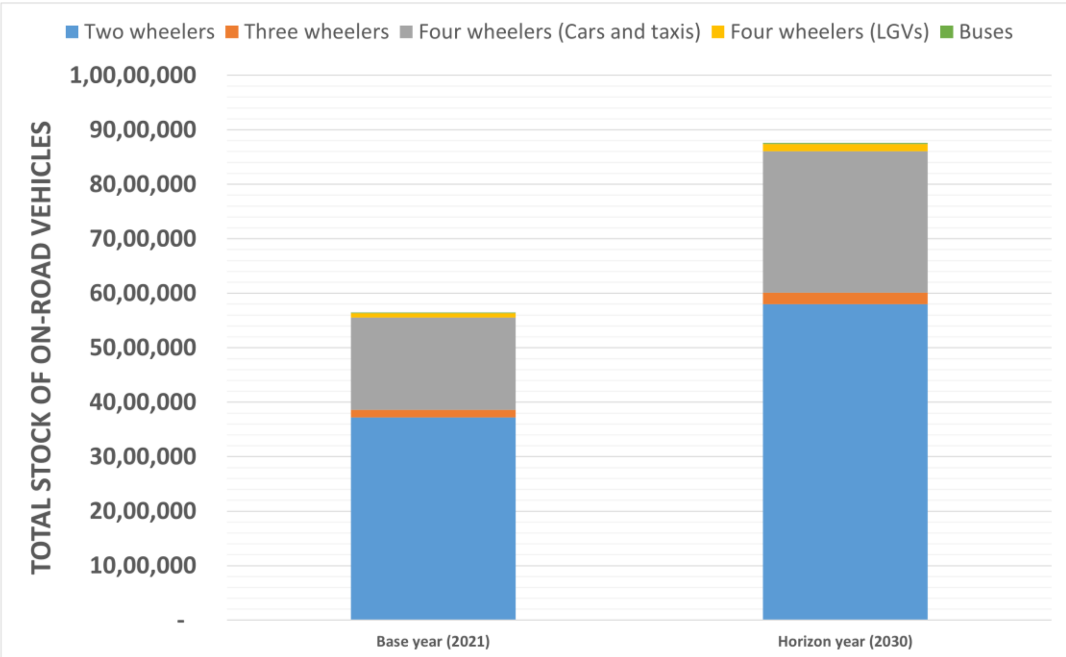


Figure 9: Growth in Bengaluru's on-road vehicle stock during 2021–2030. LGV, Light goods vehicle.

In terms of pollutant emissions, more pronounced savings can be witnessed through the EV transition. The significant adoption of electric 2Ws results in the **tailpipe emissions from 2Ws to remain nearly stagnant** for all three pollutant classes, whereas the **largest increase is witnessed in case of 4Ws**. This is because electric 4Ws showed the least EV penetration rate among all analysed vehicle classes. Overall, the **pollutant emission loads increased by 13%, 8%, and 8% for NO_x, $PM_{2.5}$, and PM_{10}, respectively**.

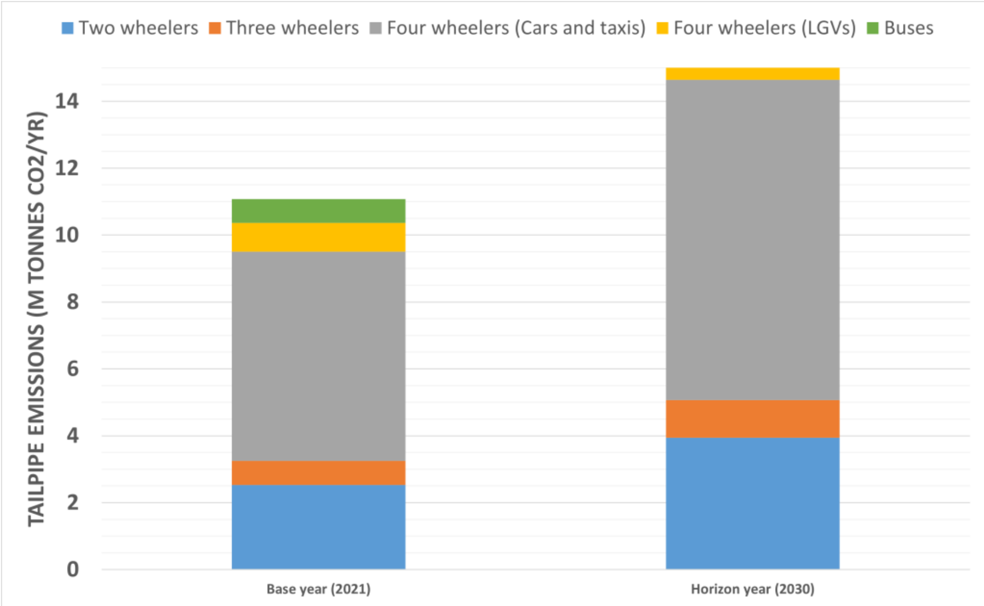


Figure 10: Increase in Bengaluru's tailpipe emissions during 2021–2030. LGV, Light goods vehicle.

The city's **EV fleet is projected to grow at a weighted average CAGR of 56%** during 2021–2030. As shown in Fig. 11, the most significant growth can be witnessed in the number of **electric 2Ws** (**2M vehicles in 2030**), followed by **electric 4Ws (140k vehicles in 2030)** and **electric 3Ws (130k vehicles in 2030)**. Together, electric LGVs and buses are projected to make up less than 45k vehicles of the total on-road EV stock in 2030. If this growth is sustained till the horizon year, **all vehicle classes, except 4Ws, would experience 100% EV sales penetration in 2030**.

Finally, for a completely green transition, the requisite size of solar PV installations to provide all the energy needed by the projected EV fleet in 2030 was calculated. Overall, **6.2 million units of electricity would be needed to charge the EV fleet on a daily basis**. To generate this energy from **solar PV**, **1.37 GW of RTPV installations** would be needed across the city, requiring a rooftop area of roughly **16.4 sq km**.

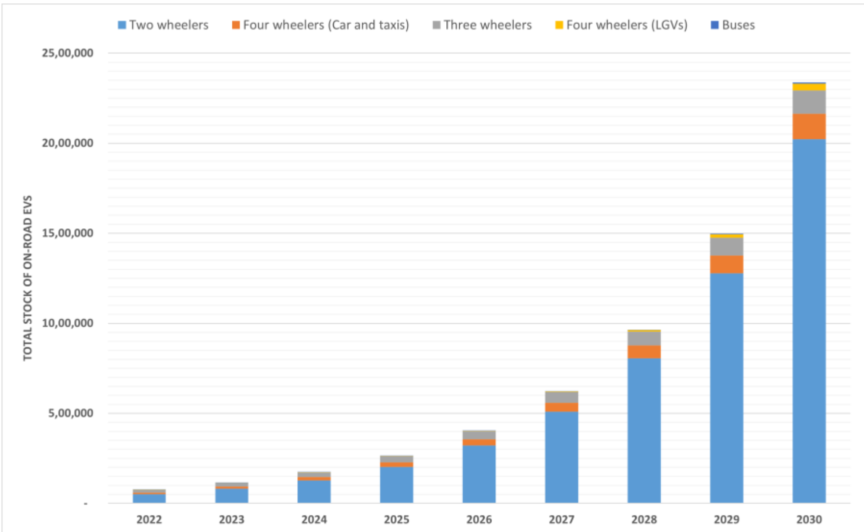


Figure 11: Cumulative growth in the electric vehicle (EV) stock during 2021–2030. LGV, Light goods vehicle.

The current analysis projected trends in Bengaluru's vehicular tailpipe emissions for the next 7 years. Based on these data, the following tasks are recommended:

- An in-depth analysis on the feasibility of various renewable energy deployment pathways (net-metering, open access, behind the meter, and solar + battery);
- Consultations involving various stakeholders (such as EV manufacturers, EV charging point operators, BESCOM officials, and relevant government bodies) to ascertain the feasibility of the study projections and obtain unbiased perspectives on future tasks to meet the required targets;
- Development of vehicle class-specific strategies to promote electrification; and
- Preparation of an action plan for policymakers to achieve the projected targets within the proposed timeframes.

This study demonstrated how the mass adoption of EVs could significantly reduce pollutant levels and GHG emissions in Bengaluru. Continuing the rapid growth witnessed in EV sales over the last few years, a significant vehicular population is expected to shift to sustainably run EVs by the turn of the decade.

13. References

Bengaluru Metropolitan Transport Corporation (2018). *Annual Administration Report (2016–17)*.

CSTEP. (2022). Emission inventory and pollution reduction strategies for Bengaluru. (CSTEP-RR-2022–4). https://cstep.in/publications-details.php?id=1985

CSTEP's "Rooftop Evaluation for Solar" Tool. (2018). Retrieved from https://crest.cstep.in/crest/#/.

Godel, P., Bieker, G., & Bandivadekar, A. (2021). Battery capacity needed to power electric vehicles in India from 2020 to 2035. The International Council on Clean Transportation. https://theicct.org/publication/battery-capacity-needed-to-power-electric-vehicles-in-india-from-2020-to-2035/

Harish, M. (2012). A study on air pollution by automobiles in Bangalore city. *Management Research and Practice*, 4(3), 25–36. https://mrp.ase.ro/no43/f3.pdf

India Energy Storage Alliance (2022). India's EV market to grow at CAGR of 44% between 2020-2027: IESA report. https://indiaesa.info/images/pdf/press_release/Press_release-Indias_EV_market_to_grow_at_CAGR_of_44_between_2020-2027._421564396.pdf

Infrastructure Development Corporation (Karnataka) Limited (2019). *Comprehensive Mobility Plan for Bengaluru*. https://dult.karnataka.gov.in/assets/front/pdf/Comprehensive_Mobility_Plan.pdf

Karnataka Transport Department. (2021). *Monthwise vehicle statistics report*. https://transport.karnataka.gov.in/info-4/Reports/Monthwise+Vehicle+Statistics+Report/en.

König, A., Nicoletti, L., Schröder, D., Wolff, S., Waclaw, A., & Lienkamp, M. (2021). An overview of parameter and cost for battery electric vehicles. *World Electric Vehicle Journal*, 12(1), 21. https://doi.org/10.3390/wevj12010021

NITI Aayog, WRI India and Ministry of Power, Govt. of India (2021). *Handbook of electric vehicle charging infrastructure implementation*. https://www.niti.gov.in/sites/default/files/2021-08/HandbookforEVChargingInfrastructureImplementation081221.pdf

Pandey, A., & Venkataraman, C. (2014). Estimating emissions from the Indian transport sector with on-road fleet composition and traffic volume. *Atmospheric Environment*, 98, 123–133. https://doi.org/10.1016/j.atmosenv.2014.08.039

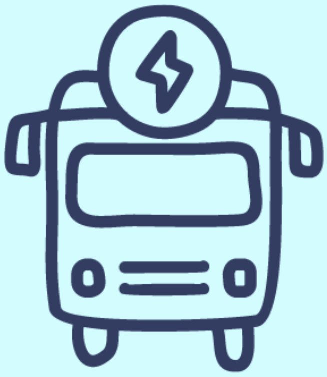
Peshin, T., SenGupta, S., & Azevedo, I. M. L. (2022). Should India move towards vehicle electrification? Assessing life-cycle greenhouse gas and criteria air pollutant emissions of alternative and conventional fuel vehicles in India. *Environmental Science and Technology*, 56(13), 9569–9582. https://doi.org/10.1021/acs.est.1c07718

Mishra, S. (2022, June 10). E-3Ws Outsell ICE in May for the first time ever; here is how the Sector is transforming. *ET Auto*. https://auto.economictimes.indiatimes.com/news/commercial-vehicle/lcv/3ws-in-spite-of-ice-segment-recovery-electrification-makes-rapid-strides/92122168

Singh, R., & Banerjee, R. (2015). Estimation of rooftop solar photovoltaic potential of a city. *Solar Energy*, 115, 589–602. https://doi.org/10.1016/j.solener.2015.03.016

Transport Research Wing, Ministry of Road Transport and Highways, Government of India (2013). Road Transport Year Book (2011-12). https://morth.nic.in/sites/default/files/Road_Transport_Year_Book_2011_12.pdf

Wang, Y., Yang, L., Han, S., Li, C., Ramachandra, T. V. (2017). Urban CO2 emissions in Xi'an and Bangalore by commuters: implications for controlling urban transportation carbon dioxide emissions in developing countries. *Mitigation and Adaptation Strategies for Global Change*, 22, 993–1019. https://doi.org/10.1007/s11027-016-9704-1



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