TRANSITION TO ALL-ELECTRIC PUBLIC TRANSPORTATION: ENERGY RESOURCE ASSESSMENT

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Transition to All-Electric Public Transportation: Energy Resource Assessment

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Center for Study of Science, Technology and Policy (CSTEP)

June, 2018

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This report should be cited as: Sridhar, H., Thirumalai N.C., Bharadwaj, M., Dash, V., (2018). *Transition to All Electric Public Transportation: Energy Resource Assessment*, (CSTEP-Report-2018-11).

June, 2018

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Executive Summary

There has been a surge of interest regarding the adoption of electric vehicles (EV). The idea of large-scale penetration of EV presents a new set of sectoral planning challenges. This move will require coordinated planning between three sectors: transportation, urban planning and power.

In this report, we examine the 'Transition to All-Electric Public Transportation', focusing on the charging energy requirement in 2030. This assessment pertains to select four-wheeler taxi categories and public buses. We also explore the role of renewable energy and estimate the contribution of fossil-free generation sources, in terms of energy and equivalent capacity addition, to support this need. Inclusion of this additional capacity will help India realise its Nationally Determined Contribution (NDC) targets. In terms of charging energy needs for routine operation, EV would require about three times less energy than diesel-based transport. Considering the growth rate indicated by the Ministry of Road Transport and Highways, and assuming 100% EV adoption by 2030 for the vehicle segments considered in this study, the additional annual energy requirement is estimated to be around 76 Billion Units (BU). The fossil-free generation capacity needed in addition to the planned generation (for 2030) works out to be around 23 GW.

Acknowledgements

CSTEP is grateful for the core support provided by the International Development Research Corporation (IDRC) and Oak Foundation, which made this report possible.

The support and encouragement provided by Dr Anshu Bharadwaj, Executive Director, CSTEP are deeply appreciated.

We would like to thank Dr S.S. Krishnan, Advisor, CSTEP and Dr Jai Asundi, Research Coordinator for their critical review of this report.

We are grateful to Dr C.P. Anil Kumar for his valuable suggestions and advice.

Thanks are also due to our CSTEP colleagues Devaditya Bhattacharya, Merlin Francis, Arushi Sen, and Aswathy Shivaji for providing editorial support and graphics inputs.

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1. Introduction

There has been an enhanced interest towards increasing the share of electric vehicles (EV) in the transportation mix. The Power Ministry has recently indicated the possibility of an all-electric transport sector by 2030[1]. In this pursuit, there is a need to estimate the additional energy required year on year, to facilitate the transition towards an all-electric public transportation system.

To foster the growth of EV, the Ministry of Heavy Industries and Public Enterprises has taken the following steps:

- Under the National Electric Mobility Mission Plan, 2013 (NEMMP) 6–7 million (60–70 lakhs) EV/hybrid vehicles have been envisioned to be deployed on Indian roads by the year 2020.
- Under Faster Adoption and Manufacturing of (Hybrid &) Electric vehicles in India, 2015 (FAME India), the government had set aside funds to subsidise EV purchases. For the year 2017-18, Rs. 175 crore has been allocated[2]. Further, the government aims to provide fiscal and monetary incentives. With support from the government, the cumulative EV sale is expected to reach 15-16 million units (1.5 to 1.6 crore) by 2020[3].

Through these schemes, the government aims to enable hybrid and electric vehicles to become the preferred choice for consumers. This will lead to reduced oil consumption in India by the automobile sector, thereby reducing the petroleum import bill and improving energy security as well as air quality.

2. Estimation of Growth of Public Transport Vehicles

A significant aspect of all existing public transport vehicles going electric is that an entire sector that was dependent on petrol, diesel and compressed natural gas (CNG) is moving towards a different source of energy—electricity. The magnitude of this modal shift would make the public transport sector a subset/component of the power sector with its own energy needs. In this context, it is important to examine the implications on the additional energy requirement to enable this modal shift.

Figure 1[4] illustrates the transportation sector mix (MoRTH, 2016). It is evident that in terms of sheer numbers, two-wheeler (2W) vehicles constitute the major share at approximately 73% of the total number of vehicles. In the four-wheeler (4W) segment, 2.26 million (of a total of 28.6 million) vehicles fall under the taxi category. This constitutes about 8% of the 4W segment and 1% of the total registered vehicles. With a focus on public transportation, we consider only select categories under the 4W taxis and buses. A detailed classification of the segment and choice of data projection are presented in the Appendix.

[1] http://economictimes.indiatimes.com/industry/auto/news/industry/india-aims-to-become-100-e-vehicle-nation-by-2030-piyush-goyal/articleshow/51551706.cms
[2] http://indianexpress.com/article/blogs/100-electric-vehicle-mobility-by-2030-is-india-really-prepared-for-it/
[3] http://pib.nic.in/newsite/PrintRelease.aspx?relid=116719
[4] 'Four wheeler' segment includes cars, jeeps and taxis; 'Bus' segment include buses and Omni buses; 'Goods Vehicle' segment includes trucks, lorries and light motor vehicles (LMV); 'Others' segment includes auto rickshaws, tractors, trailers, three-wheeler passenger and miscellaneous.

Under the 4W segment, we consider only the categories that are adapted to carry less than six passengers, excluding the driver, for hire or reward[5]. Also, considering the drive cycle[6] details assumed in the analysis, we further limit our consideration to ordinary taxis and motor cabs with state permit. This accounts for 3.1% of the 4W segment and 0.42% of the total number of vehicles. Similarly, we consider only the public buses run by state transport undertaking (STU) category under the bus segment. This accounts for 7.13% of the bus segment and 0.07% of the total number of vehicles. These small percentage shares still merit analysis as we have to acknowledge the fact that charging energy needs vary significantly across vehicle segments[7]. Table 1 indicates the statistics pertaining to the number of registered vehicles under the select 4W taxis and bus segments for 2015.

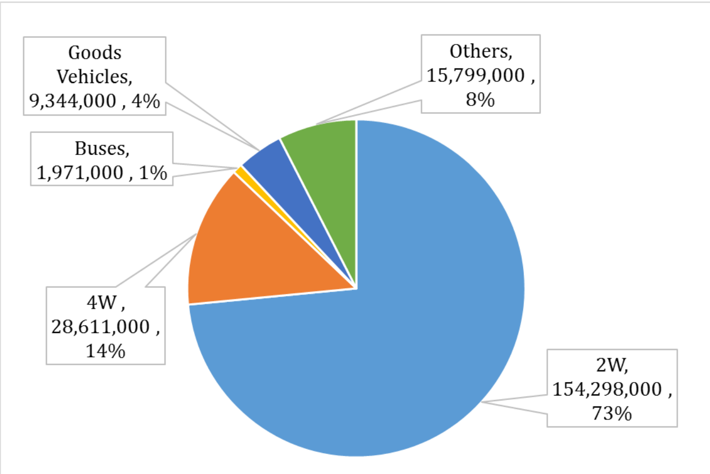


Figure 1: Share of vehicles for 2015 (MoRTH, 2016)

Table 1: Statistics for selected vehicle categories for 2015 (MoRTH, 2016)

Vehicle Type	Numbers	CAGR* (2005 to 2015)
4 W – taxis (Ordinary and Motor Cabs with State permit)	8,90,233	10.7%
Buses (Public STU)	1,40,497	2.17%

*Compound Annual Growth Rate

The total number of vehicles in these categories was approximately 1.03 million in 2015. We consider three paths of growth rates:

1. At 50% CAGR (0.5x CAGR)
   - This could be associated with a scenario of lower adoption of bus and taxi–based transportation due to enhanced implementation of Mass Rapid Transportation Systems (MRTS) and metro rail systems.
2. At CAGR
   - This could be associated with a scenario of business-as-usual (BAU) case.

[5] Definition of motor cabs as per section 2(22) and 2(25) of the Motor Vehicles Act, 1988, (MoRTH, 1988)
[6] Typically captures the behaviour/drive pattern of the vehicle over time. It can be used to assess the performance of vehicles in terms of fuel consumption, polluting emissions etc.
https://en.wikipedia.org/wiki/Driving_cycle
[7] Based on the type of vehicle, 2W battery ranges from 1.6 kWh (Hero Electric Photon) to 27 kWh (UM Renegade Thor), 4W battery size varies from 13.5 kWh (Mahindra e20+) to 24 kWh (Nissan Leaf), bus battery size typically are about approximately 320 kWh (Tata Versa, Goldstone BYD buses).

3. At 150% CAGR (1.5x CAGR)
   - This could be associated with a scenario of higher adoption of bus and taxi–based transportation due to sub-par adoption of MRTS and metro rail systems and also reduced purchase of private vehicles.

We estimated the projected growth of vehicles in terms of numbers for 4W taxis and buses from 2018 to 2030. Figure 2 and Figure 3 present this data for the selected years. Figure 4 indicates the corresponding percentage shares. We can observe that the percentage breakup with respect to the number of taxis and buses ranges from 88% and 12% in 2018 to 97% and 3% in 2030. To put this growth in perspective, we estimated the total number of vehicles under these two segments by 2030 to be between 2.11 and 8.53 million. This is a two to eight fold increase with reference to 2015 data (1.03 million).

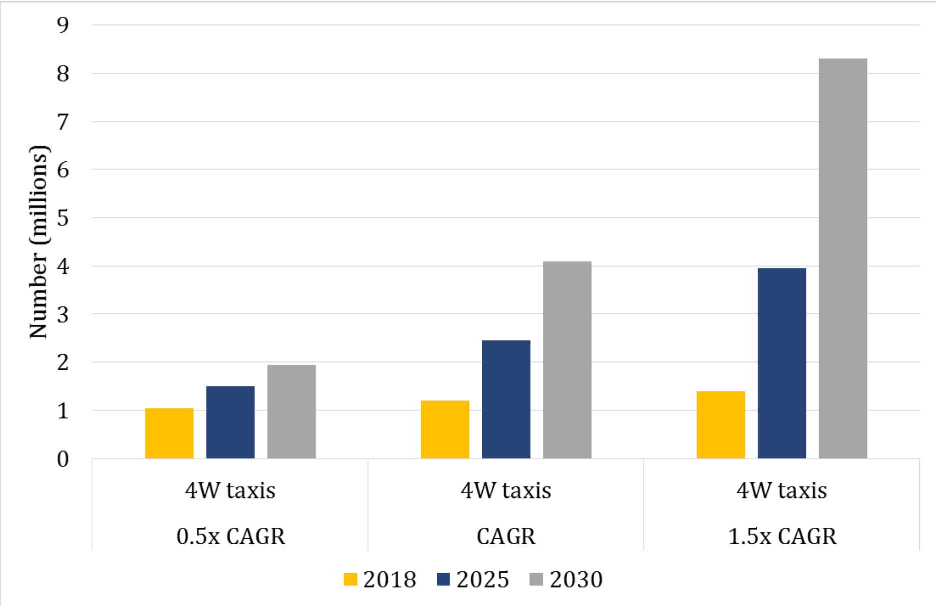


Figure 2: Projection for number of 4W taxis

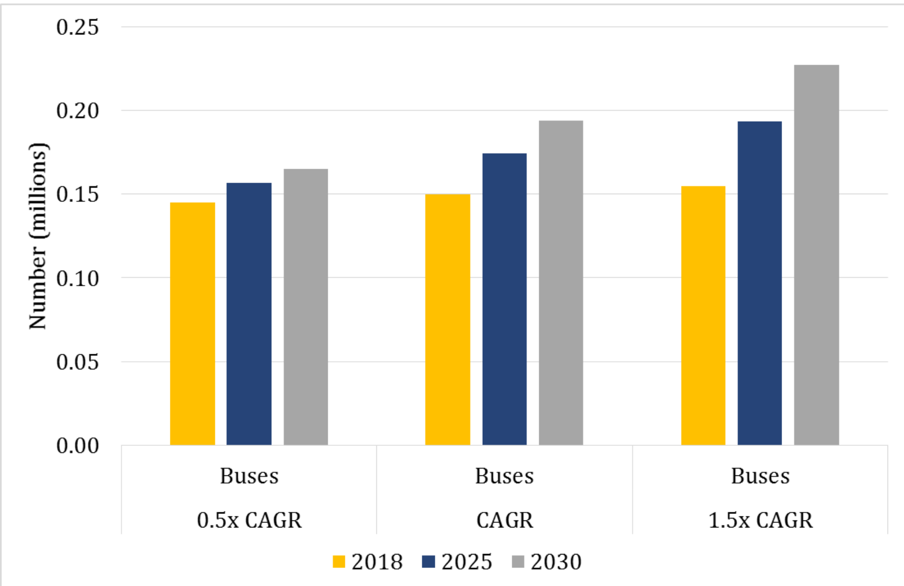


Figure 3: Projection for number of buses

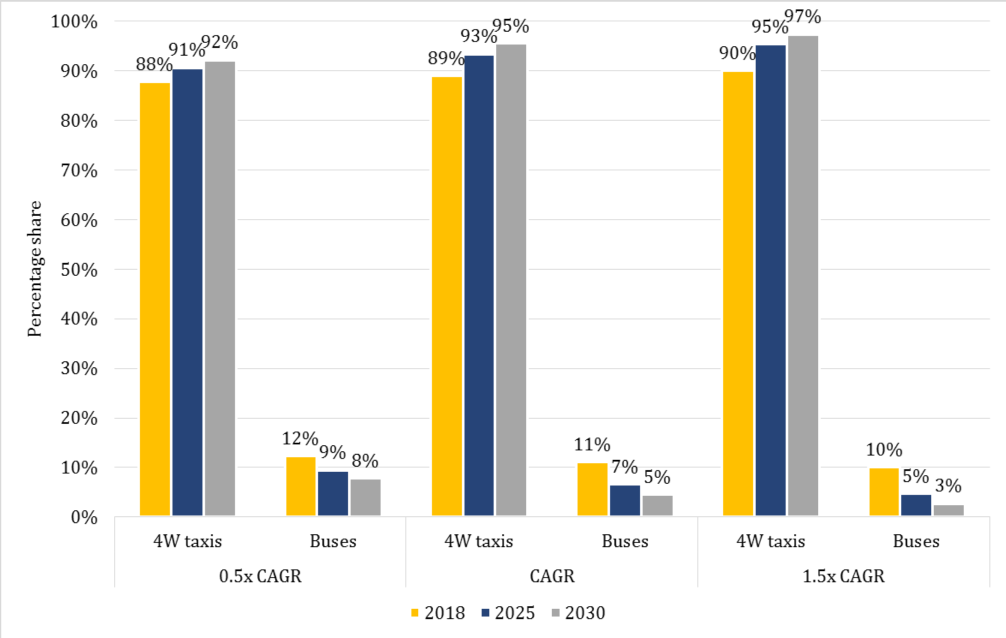


Figure 4: Segment-wise percentage breakup of number of vehicles

3. Comparison between Diesel Vehicles and EV

Understanding the daily operational details for a diesel vehicle and EV would lay an appropriate basis for examining the benefits of switching to EV. We consider the per-day travel range, battery sizes, mileage and other aspects of estimating energy requirement in consultation with sector experts. Table 2 lists the typical operation parameters of EV that are considered to estimate the energy requirement. Further, we assume the power circuit efficiency of the charging infrastructure ($\eta_{charging}$), the battery energy efficiency ($\eta_{battery}$) and the battery-to-propulsion efficiency ($\eta_{propulsion}$) to be 92%, 95% and 80%, respectively. This corresponds to a system efficiency[8] (η_{system}) of approximately 70%.

$$\eta_{system-EV} = \eta_{charging} * \eta_{battery} * \eta_{propulsion}$$

$$Energy\ from\ supply\ mains\ per\ day = E_{source-EV} = \frac{Battery\ size * Number\ of\ charges/day}{\eta_{charging} * \eta_{battery}}$$

Table 2: Operation parameters of EV (per vehicle)

Vehicle type	Average travel per day (km)	Range [a] (km/charge)	Number of charges/day	Battery size (kWh)	Energy from supply mains for charging (kWh)/day
4W – EV (NISSAN USA, 2016)	150[9]	172.27[10]	0.87	30	30[11]
Bus – EV (BYD, n.d.)	300	250	1.2[b]	324	446[8]

[a] Considering current front runner electric cab and bus models; [b] considering mid-day top up charging

[8] η_{system} = power circuit efficiency * battery energy efficiency * battery-to-propulsion efficiency
[9] Taxis in bigger cities may have larger trip lengths, but on an all-India average, a range of 150 km is assumed.
[10] Considering Nissan Leaf SV 2017 model, range: 107 miles ~ 172.27 km.
[11] Energy supply from mains = no. of charges per day * battery size/(charging efficiency * battery energy efficiency)

Similarly, we consider the operation parameters of diesel-based vehicles under the segments of interest (in Table 3) after consultation with respective operators.

Table 3: Operation parameters of diesel vehicles (per vehicle)

Vehicle type	Average range per day (km)	Engine, system efficiency ($\eta_{system-diesel}$)	Mileage (km/L)	Fuel consumption (L)/ Day	Energy from fuel[c] (kWh)/day
4W - Diesel	150	20%	14	10.71	106.89
Bus - Diesel[12]	300	25%	2.25	133.33	1,330.21

[c] *Considering the net calorific value (NCV) of diesel to be 9.98 kWh/L*

$$Energy\ from\ fuel\ per\ day = E_{source-diesel} = Fuel\ consumption\ per\ day * NCV\ of\ fuel$$

An illustration of the per-day energy flow is indicated in Figure 5. Here, the energy from source to that used in propulsion ($E_{propulsion}$) is obtained by the following relation:

$$E_{propulsion\ diesel/EV} = E_{source-diesel/EV} * \eta_{system-diesel/EV}$$

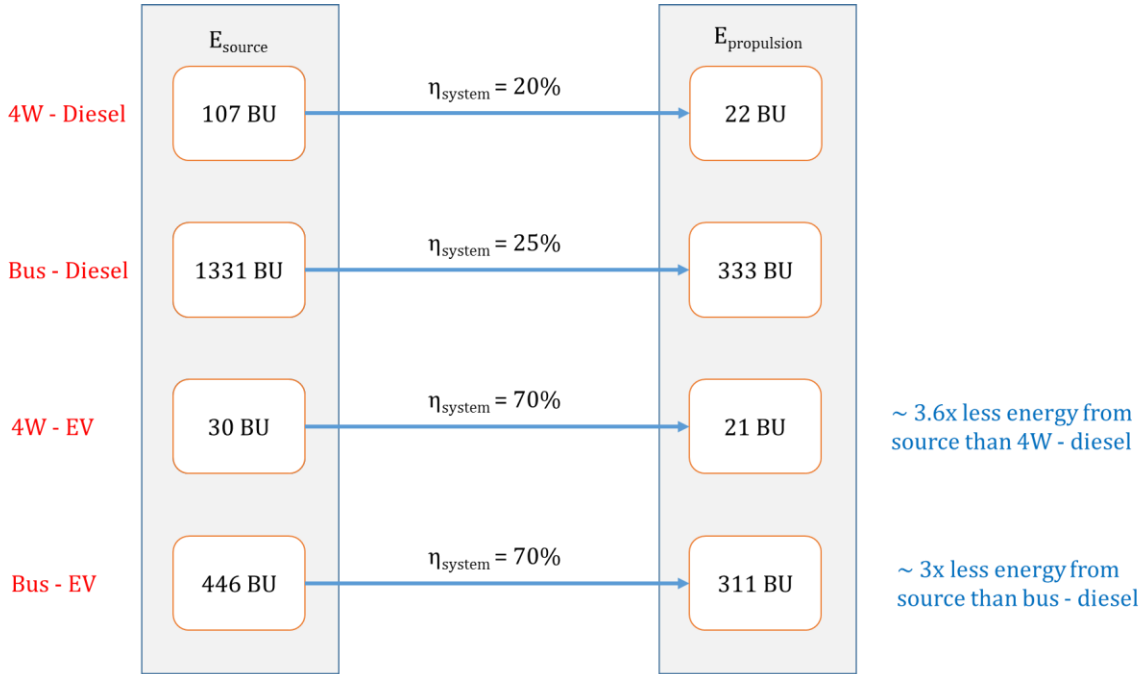


Figure 5: Flow of energy requirements from source to wheel/propulsion

The ratio of the energy consumed by a diesel to an EV variant is approximately 3.6:1 for 4W taxis and around 3:1 for buses. It can be seen that EV are certainly more efficient technologies in terms of sheer energy requirement to cover the same distance. If we consider a case where there is no EV penetration by 2030, the diesel (fuel) needs, considering the above-mentioned operational parameters and path of growth adopted, would be as per the indications in Figure 6. This could be converted to the aggregate equivalent energy in terms of BU to offer an overall perspective, as illustrated in Figure 7.

[12] Considering buses with air conditioning units (AC) for both the diesel and EV variants

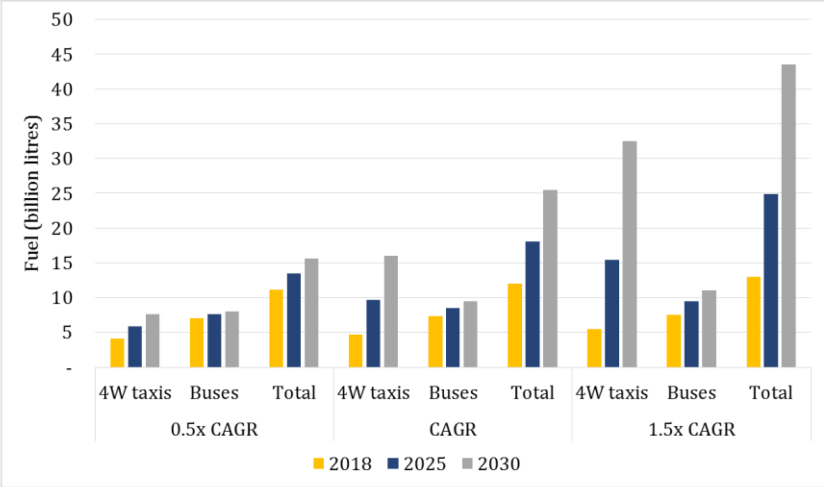


Figure 6: Fuel requirement for diesel-based vehicles in a no EV scenario

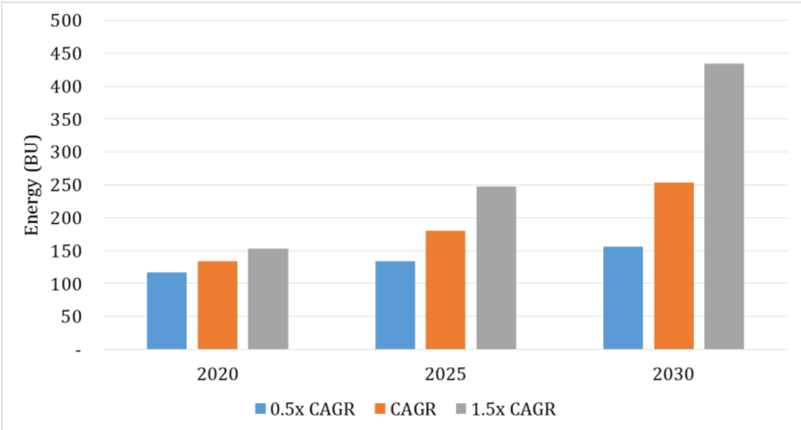


Figure 7: Aggregate equivalent energy for diesel-based vehicles in a no EV scenario

Now let's consider a hypothetical case in which, for a given target year, all registered vehicles in these segments convert to EV. Here, energy requirement would be estimated purely for charging the vehicles under three chosen growth rates.

Figure 8 illustrates this, considering daily energy needs as per Tables 2 and 3. This exercise is to provide a projection for the scale of transformation required in the energy sector[13]. Figure 9 indicates the percentage breakup of energy requirement for this scenario, and Figure 10 indicates the aggregate charging energy needs per year for this case. It is to be noted that when the adoption rate is at par with CAGR or 1.5x of CAGR, at some point before 2030, the energy requirement from 4W taxis constitute a higher percentage share when compared with buses. This is due to the higher growth rate associated with 4W taxis. Also, compared with the energy needs from diesel, EV require over three times less energy for accomplishing the same operating characteristics.

[13] Although, in a realistic scenario, the adoption would be on a more gradual rate.

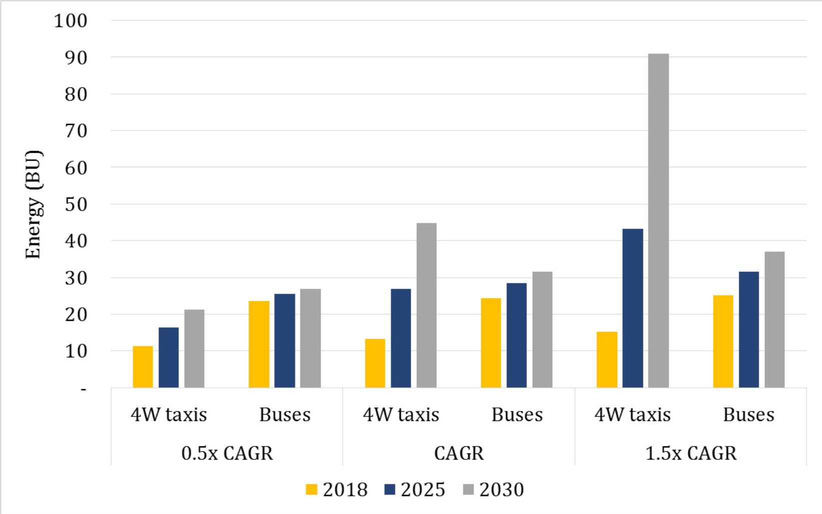


Figure 8: Category-wise quantum of energy required for EV under three CAGR scenarios

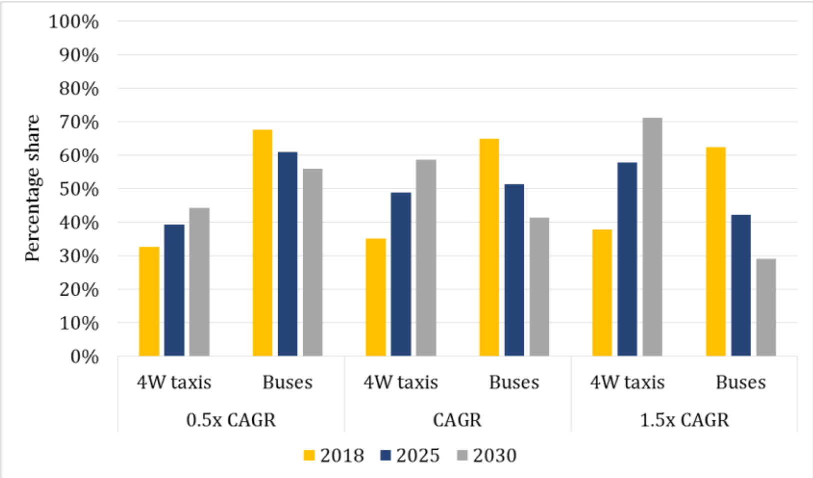


Figure 9: Percentage breakup of energy requirement for EV

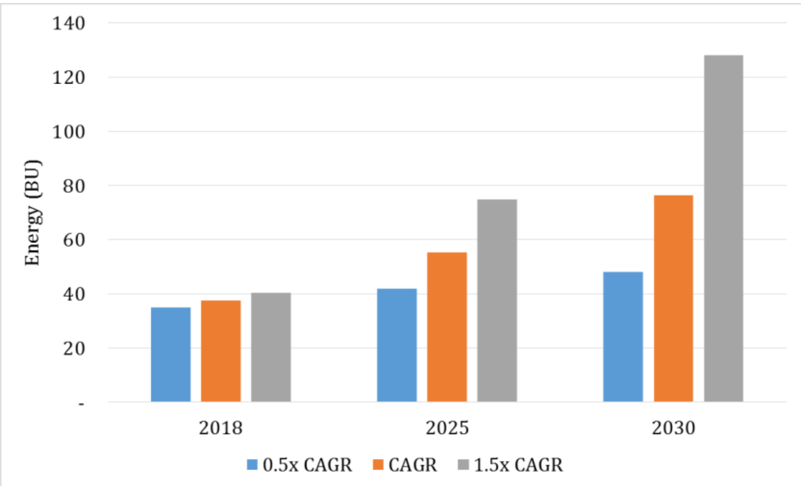


Figure 10: Aggregate energy required for EV in Billion Units

4. Focusing on 2030

We consider 2030 as a year of interest because it aligns with the target year for India's Nationally Determined Contribution (NDC) goals. Figure 11 and Figure 12 reiterate the number of 4W taxis and buses and the corresponding energy requirement for a complete EV transition in these segments. In reality, however, this transition would occur in a phased manner. To address this, in this study we consider four adoption levels (25%, 50%, 75% and 100%) in tandem with the three growth rates considered earlier. The objective is to provide a perspective for stage-wise adoption.

It should be noted here that while the government aims to sell only EV beyond 2030[14], there will still be a significant number of petrol and diesel–based vehicles in operation. Thus, it would be prudent to state that the transportation sector will still have a strong dependency on oil to cover its energy needs. Nonetheless, with the transition towards EV, the transportation sector would see a reduction in the proportion of oil imports. The power sector would have to consider these energy needs along with the existing demand for sectoral planning.

To summarise, by 2030 the total number of vehicles in these segments could range from 2.11 to 8.53 million (across three CAGR levels). This could correspond to an additional annual charging energy requirement ranging from 48 BU to 128 BU. To put this in perspective, the total electrical energy requirement from the power sector for the year 2030 would be approximately 2435 BU[15,16]. Figure 13 illustrates the charging energy requirement for EV as a percentage of the total electrical energy requirement of the power sector for 2030. Currently, the all-India installed generation capacity is approximately 334 GW, of which the fossil-free generation capacity[17] contributes to around 115 GW (34%) and the energy needs stand at approximately 1230 BU (CEA, 2017).

[14] http://money.cnn.com/2017/06/03/technology/future/india-electric-cars/index.html

[15] Obtained by interpolating India's electric energy requirement, as per the 19th Electric Power Survey (EPS) summary http://www.cea.nic.in/reports/others/planning/pslf/summary_19th_eps.pdf

[16] It is to be noted that the EPS estimates cover only for the projections of utility systems. These projections do not include the portions of electricity demand of industries and other consumers that would be met from captive power plants.

[17] Fossil-free generation is the total capacity contribution from nuclear energy, large hydro systems and renewable energy systems (RES) as defined by Central Electricity Authority (CEA).

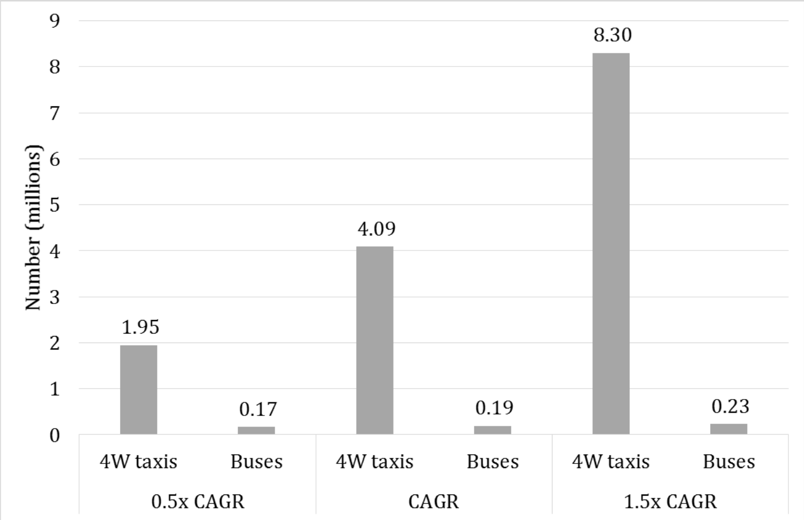


Figure 11: Projected number of EV in 2030

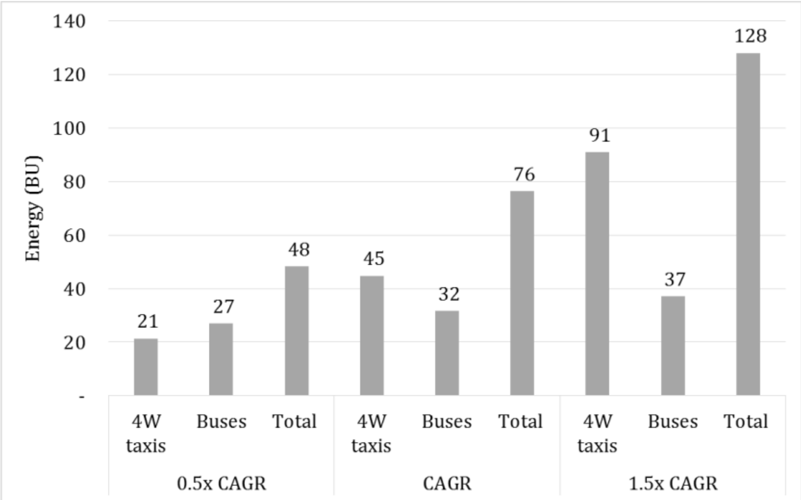


Figure 12: Projected charging energy requirement for EV in 2030

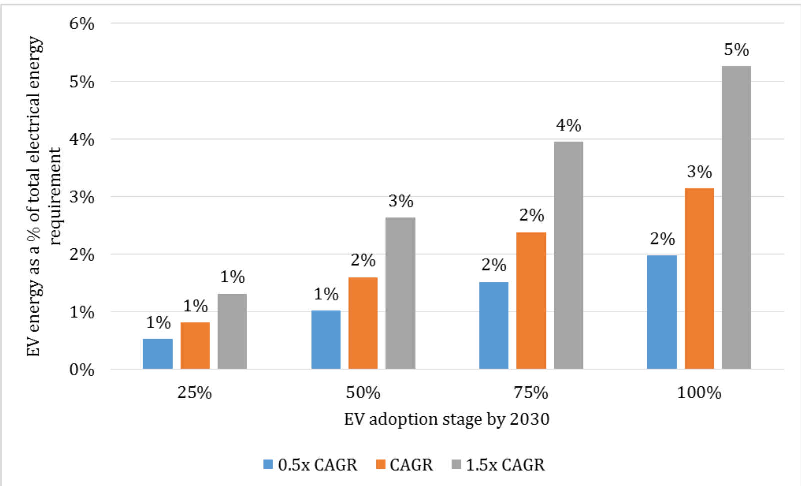


Figure 13: Aggregate charging energy requirement for EV as a percentage of the total electrical energy requirement from power sector for 2030, as per 19th Electric Power Survey (EPS)

5. Nature of Energy Requirement

In order to better understand the timing of the energy requirement, a pattern of energy need has been asssumed for this analysis. This pattern considers a fixed daily consumption profile. Here, the taxis and buses are charged overnight to full capacity daily and the buses, specifically, are provided an additional 'top-up' charging during their 'mid-day break' from 1 pm to 3 pm. This charging pattern for buses is aligned with a generic schedule of operation with minimal disruption. The charging schedules could change due to variations in vehicle operation practices in different cities, especially in the case of 4W taxis.

Further, it has been assumed that solar energy is available for utilisation from 7 am to 4 pm and wind energy is available from 6 pm to 5 am. This consideration has been made in terms of generic availability of solar and wind resources to provide a context for the temporal nature of resource availability. However, in reality each location has its own specific pattern of solar and wind resource availability. Moreover, the schedules for charging, in future, could be further optimised to tap the available energy sources better.

Figures 14, 15 and 16 illustrate the generic daily pattern of energy requirement for a case in 2030 for 100% adoption rate. Here, the hourly quantum energy needs vary as per the adopted growth rate and the generic profile of available solar and wind energy sources on a temporal basis.

We see that the majority of the energy requirement under this consumption pattern falls at night (when solar energy is not available). Only a portion of wind energy and base load energy (such as nuclear) would be suitable to cater to this demand. Even during the day time, we can observe that the timing of the energy requirement coincides with the trailing end of the solar energy profile. This aspect has been considered to arrive at the daily and hence the aggregate annual energy requirement, as illustrated in Figures 10 and 12. Here, the wind hours and solar profile indicate a generic/typical status of availability.

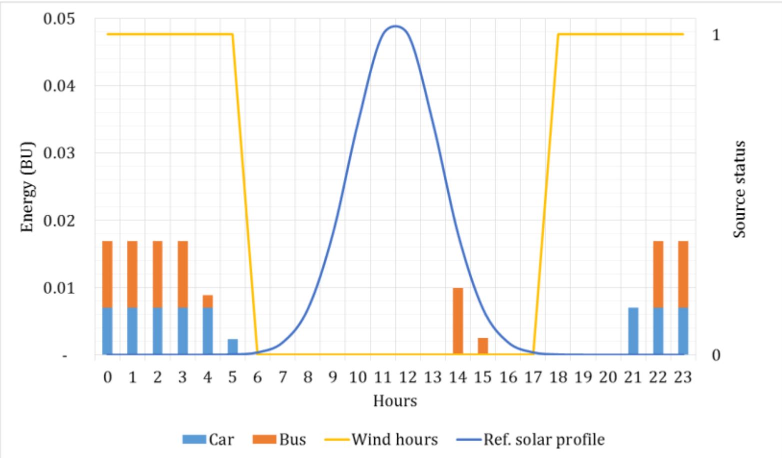


Figure 14: Daily pattern of average energy requirement along with the status of solar and wind resource availability, with a growth rate of 0.5x CAGR for 2030

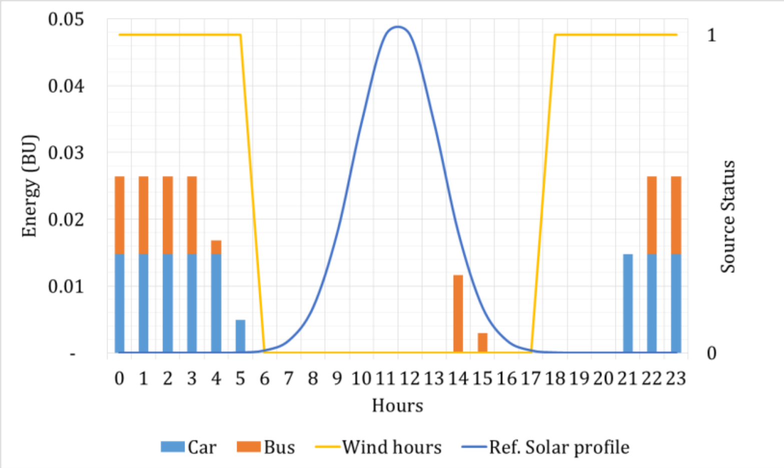


Figure 15: Daily pattern of average energy requirement along with the status of solar and wind resource availability, with a growth rate of CAGR, for 2030

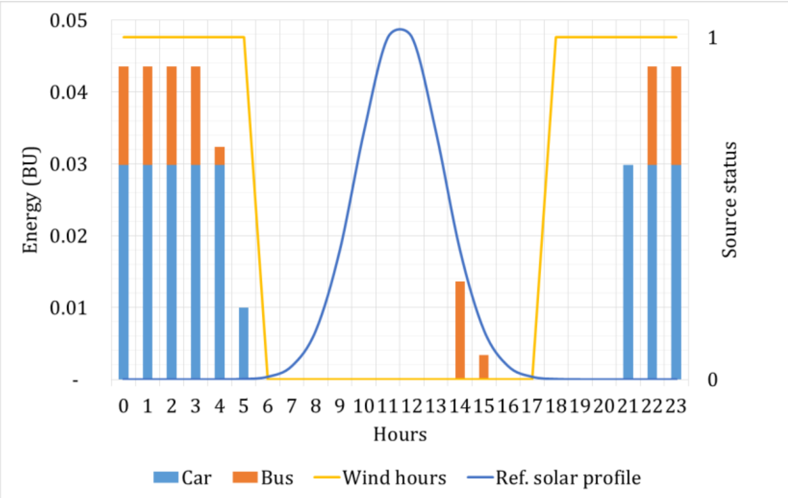


Figure 16: Daily pattern of average energy requirement along with the status of solar and wind resource availability, considering a case for 2030 with a growth rate of 1.5x CAGR.

6. Role of Renewable Energy Plants

In order to further understand the role of renewable energy (RE) plants and their contribution towards the energy requirement, an understanding of a crucial aspect of their operation is necessary. For solar photovoltaic (PV) systems, with an increase in cell efficiency, the number of modules required for a particular capacity would decrease. However, the capacity of the plant itself would remain the same. Of course, a system with more efficient panels would have a much smaller footprint area compared with the less efficient ones. With this understanding, we focus on establishing the suitable capacity of solar PV systems to support this energy need.

The availability factor (AF) of a plant is the ratio of the number of hours for which the plant has active energy generation to the total number of hours in the time period of observation. For our case, we consider the following:

$$Availability\ factor = \frac{Number\ of\ hours\ of\ generation}{8{,}760}$$

Usable solar energy is typically available for 9 hours a day. This corresponds to an availability factor of 37.5%. The definition of capacity utilisation factor (CUF) is:

$$CUF = \frac{Total\ energy\ generated}{Plant\ rated\ capacity * 8{,}760}$$

$$CUF = \frac{Average\ \ power\ generated\ per\ hour * No.of\ hours\ of\ generation}{Plant\ rated\ capacity * 8{,}760}$$

$$CUF = \frac{Average\ \ power\ generated\ per\ hour}{Plant\ rated\ capacity} * Availability\ factor$$

$$Power\ ratio = \frac{Average\ \ power\ generated\ per\ hour}{Plant\ rated\ capacity}$$

Figure 17 illustrates a sample solar generation profile. Ideally, the ratio of average power generated per hour per day to the plant rated capacity would, approximately, be the ratio of the area under the generation curve to the area corresponding to the rectangular window (power ratio). In this case, the ratio is 0.58. The pattern of the generation curve is primarily dependent on the quantum of incident solar radiation at different time intervals. The nature and distribution of this radiation may not always be as smooth as indicated in Figure 17. However, we consider a smooth profile for initial assessments. Also, the availability of energy may not always correspond to around 9 hours a day; it could be less than that, depending on the season. Nonetheless, we consider a conservative power ratio of 0.5. Multiplying this power ratio with the availability factor would give the CUF estimate of **18.75%** (0.5 * 0.375 = 0.1875) for the entire country.

$$Annual\ energy\ generated = Plant\ capacity * CUF * 8760$$

In the case of wind energy systems, there are periods when the plant operates for very few hours per day. On the other hand, during monsoon, wind plants would produce energy all day long. This indicates a strong seasonal pattern in wind energy systems, which is certainly very different from solar plants. Hence, the concept of a generic availability factor may not be suitable. As per CERC,[18] the typical CUF range for wind plants in India varies from 20% to 32% (CERC, 2016). Hence, we consider a mean CUF of **26%**.

[18] Central Electricity Regulatory Commission (CERC)

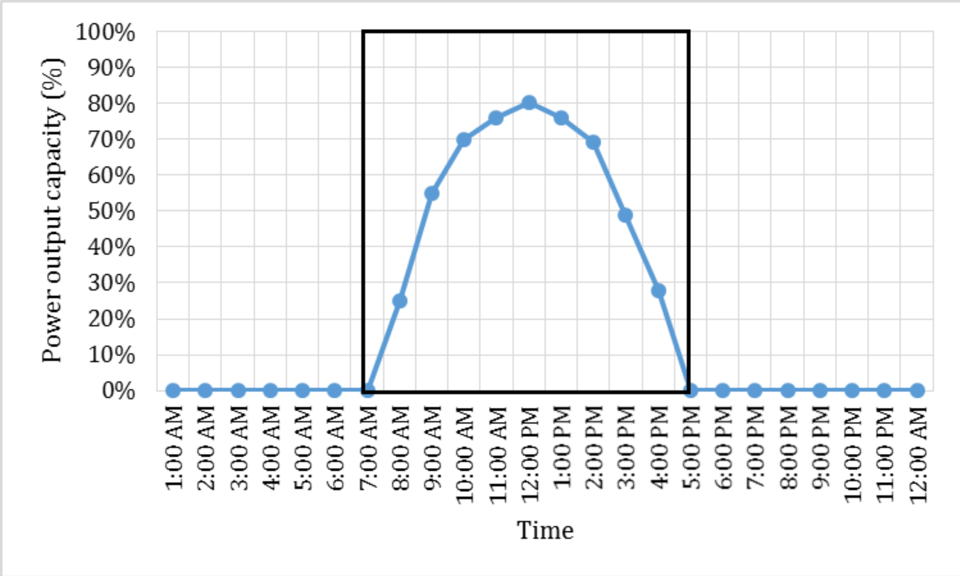


Figure 17: Sample solar generation profile for a cloud free day

7. Equivalent Generation Capacity to Meet EV Energy Requirement

We compute the equivalent generation capacity based on appropriate plant load factor (LF) and availability factor (AF) estimates[19] (in Table 4). Here, we consider only fossil-free energy sources (nuclear, solar and wind) for estimation of additional generation capacity. To account for the variation in the consumption pattern in a day (considering the CUF details), we assume a temporal generation mix based on the inferences made so far. We consider the following generation mix to meet the energy requirement:

- 60% by solar and 40% by nuclear energy from 7 am to 4 pm
- 15% by wind and 85% by nuclear energy from 5 pm to 6 am

The conservative nature of this assumption is to account for the variable/intermittent nature of wind and solar energy sources and supplement them with a firm source of energy (nuclear).

Table 4: Operational assumption for various plants

Plant type	LF %	AF %	CUF %
Nuclear	90%	80%	72%[20]
Solar	-	-	18.75%*
Wind	-	-	26%*

**as per considerations mentioned in the earlier section*

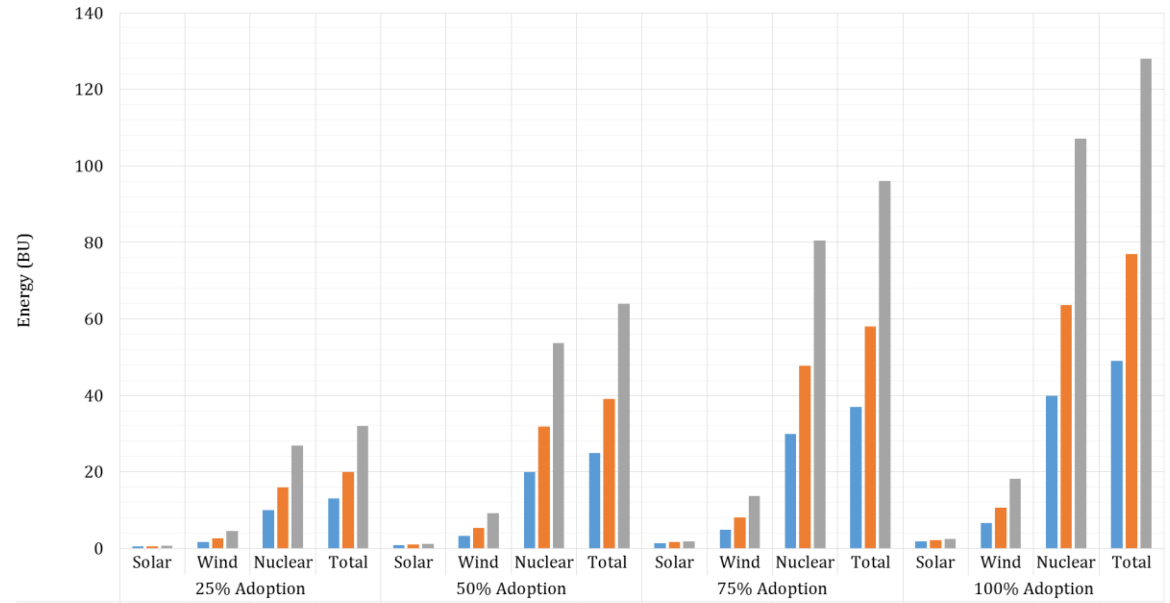
Here,
LF: Load Factor; AF: Availability Factor; CUF: Capacity Utilisation Factor

Figure 18 captures the aggregate annual energy contributions from various sources taking into account the CUF and generation mix considerations. We calculate the plant capacity as follows:

$$Plant\ capacity = \frac{Total\ energy\ required}{CUF * 8{,}760}$$

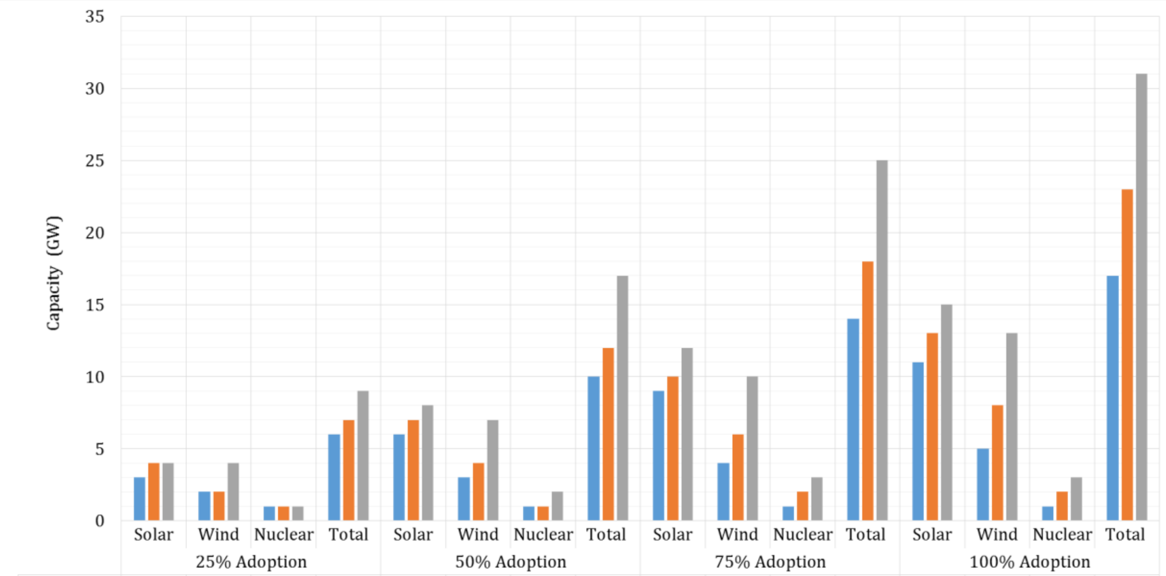
[19] As per CEA – Transmission planning criteria
[20] For conventional plants, CUF = LF * AF

Figure 19 captures the equivalent generation capacity (in GW) to support this energy requirement.



	25% Adoption				50% Adoption				75% Adoption				100% Adoption			
	Solar	Wind	Nuclear	Total	Solar	Wind	Nuclear	Total	Solar	Wind	Nuclear	Total	Solar	Wind	Nuclear	Total
0.5x CAGR	0.5	1.6	10.0	13.0	0.9	3.3	19.9	25.0	1.4	4.9	29.9	37.0	1.8	6.6	39.8	49.0
CAGR	0.5	2.7	15.9	20.0	1.1	5.3	31.8	39.0	1.6	8.0	47.7	58.0	2.1	10.7	63.6	77.0
1.5x CAGR	0.6	4.6	26.8	32.0	1.2	9.1	53.6	64.0	1.9	13.7	80.4	96.0	2.5	18.3	107.2	128.0

Figure 18: Contribution of energy needs from different fossil-free energy sources for 2030



	25% Adoption				50% Adoption				75% Adoption				100% Adoption			
	Solar	Wind	Nuclear	Total	Solar	Wind	Nuclear	Total	Solar	Wind	Nuclear	Total	Solar	Wind	Nuclear	Total
0.5x CAGR	3	2	1	6	6	3	1	10	9	4	1	14	11	5	1	17
CAGR	4	2	1	7	7	4	1	12	10	6	2	18	13	8	2	23
1.5x CAGR	4	4	1	9	8	7	2	17	12	10	3	25	15	13	3	31

Figure 19: Equivalent generation capacity needs from different fossil-free energy sources for 2030

We can see that the lower CUFs of solar- and wind-based systems result in a larger share of capacity to support a given energy need. The timing of the energy need (charging time of EV fleets) would play a crucial role in determining the contribution of RE sources. An optimal scheduling of charging requirement should be worked out for the effective utilisation of energy from RE. From Figures 12, 13 and 19, *considering the energy needs for charging, its proportion with respect to projected electric energy needs of the power sector and equivalent capacity to support this need, we can say that with streamlined efforts, 100% of the segments considered can be electrified.* If not 100%, we can pursue a conservative adoption level of at least 75% by 2030. To make this successful, coordinated planning between the road transport and power sectors is essential. The power system capacity expansion plans would have to factor this additional requirement along with suitable planning for transmission and distribution (T&D) infrastructure.

8. Upgradation of T&D Infrastructure

To provide a perspective on the impact of the power required by EV on the grid, we compare it with the power rating of typical domestic appliances, in Figure 20. Considering the current options indicated by the Department of Heavy Industry, we have a slow-charging AC charging option, 3.3 kW (BEV – AC001), and fast-charging DC options (BEV – DC001) of 10 and 15 kW. For a four wheeler, the charger load of 3.3 kW is a little over the sanctioned load for a two-bedroom apartment. Similarly, the 10 kW charger matches the rated power consumption of two three-bedroom apartments, and the 15 kW charger corresponds to three three-bedroom apartments[21]. In the case of a bus during charging, the charger load (60 kW) is approximately equivalent to 12 three-bedroom apartments consuming energy at the sanctioned/connected load capacity. This is a significant addition of demand to the immediate point of connection, that is, the first distribution transformer in the line. If there is a plan for significant uptake of EV in a given location, then strategic distribution assets would require strengthening. This is necessary to accommodate seamless EV adoption with appropriate system contingency requirements. Detailed demand forecasting and power system studies of the distribution network are essential to identify the assets that require strengthening.

We need to tailor the T&D infrastructure upgrade to accommodate the considerations of urban planning and transportation sectors. We also need to perform a careful examination of EV penetration to come up with a suitable mix of MRTS, metro, 4W and bus-based transportation systems. This would cause minimal road transport congestion and local air pollution, which is already a significant problem in major cities across the country. Of course, the mix would vary from city to city. A detailed study considering a three-pronged approach, factoring constraints of the power, transportation and city/urban planning sectors, would be a requisite for a more practically implementable way forward.

[21] Here, we consider the sanctioned load of a typical 3 BHK and a 2 BHK apartment to be 5 kW and 3 kW respectively.

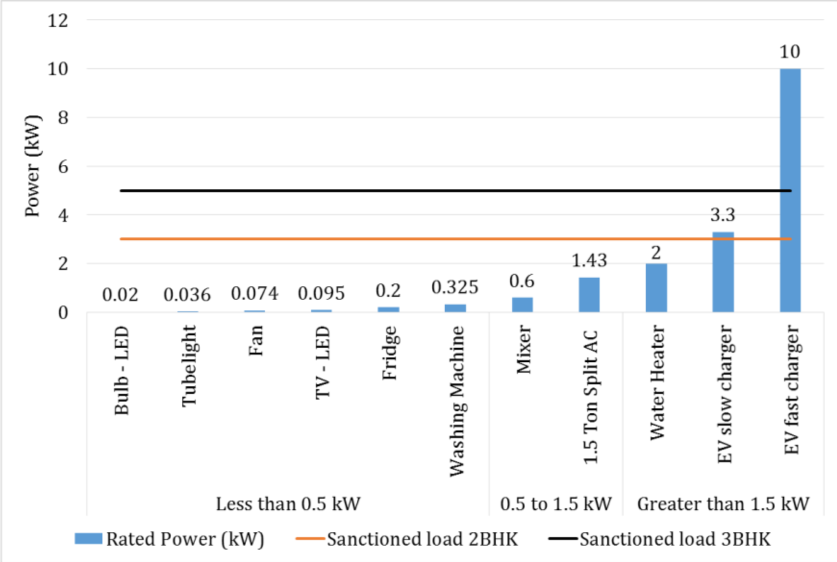


Figure 20: Comparison of power rating of typical equipment[22]

9. Summary

A preliminary analysis was performed to estimate the energy required per annum to sustain a completely EV-based public transportation system (comprising 4W taxis and buses). The NEMMP framework envisions that the number of EV would grow to 6-7 million by 2020, and under the FAME India programme, the government has provided incentives to support the sales of EV (to boost the sales to 15-16 million by 2020). In this study, we have considered the projection of vehicle growth as per estimates in the Road Transport Yearbook, 2014-15, published by the Ministry of Road Transport and Highways. In this analysis, under the 4W taxi segment, we consider the vehicles under 'ordinary taxi' and 'motor cab' with state permit categories. Under the bus segment, we consider the STU-operated public buses. The energy generation expansion plan is as per the declaration by Central Electricity Authority (CEA). This also factors India's Nationally Determined Contribution (NDC) commitment. In this study, we consider three growth rates for the transportation segments mentioned above in multiples of 50%, 100% and 150% of CAGR. Further, for 2030, we consider four adoption levels (25%, 50%, 75% and 100%) to put forth a stage-wise uptake of EV.

Table 5 summarises the projection of vehicles and energy requirement, and

Table 6 captures the required generation capacity addition[23] (both for 2030).

Table 5: Summary of projected vehicle numbers for 4W and buses and their aggregate energy needs

Parameter	50% CAGR	CAGR	150% CAGR
Projected total number of vehicles (in millions)	2.11	4.28	8.53
Projected total annual charging energy needs (in BU)	48	76	128

[22] Equipment ratings can vary significantly based on the choice of consumer; this representation is just to put forth a generic view. Also, the typical sanctioned load for a two- and a three-bedroom apartment is considered to be 3 and 5 kW respectively.
[23] Considering only solar, wind and nuclear energy capacities each contributing ~74%, 22% and 4% respectively to the total capacity mix.

Table 6: Aggregate additional generation capacity from fossil-free generation sources

Growth rate ↓/ Adoption stage →	25%	50%	75%	100%
	Generation Capacity in GW			
50 % CAGR	6	10	14	17
CAGR	7	12	18	23
150 % CAGR	9	17	25	31

To conclude, here is a summary of the main conclusions of our study for 2030:

- Inclusion of additional fossil-free generation capacity (based on the growth rate and adoption stage) could help India realise its NDC targets.
- We must note that the timing of the energy demand for charging EV plays a crucial role in determining the role of RE for EV. For instance, if the majority of the charging requirement occurs in the evening and night, solar energy sources would not be able to significantly support it.
- In order to conduct a deeper analysis, we should perform a detailed assessment of the transportation sector and its infrastructure, along with its limits in conjunction with the planning aspects of the power sector.
    - In the transportation sector, modelling of the traffic pattern of various segments and their corresponding behavioural patterns is important. This would include analysis of aspects such as timing of commuting, growth trajectory of the sector and limitations of the transport infrastructure. It is necessary to conduct a detailed assessment of the impact of the transition to EV on the transportation sector ecosystem. This includes aspects like phasing out the conventional vehicle fleet along with its component value chain.
    - With respect to the power sector, we should pursue modelling of the pattern of energy consumption, electricity-demand forecasting and technological advancements in storage and energy-generation systems. Finally effort must be put forth to perform detailed power system analysis to understand the implications on the power grid and lay suitable system expansion plans.

10. References

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11. Appendix

Figure 21 provides a detailed classification of the road transportation sector (MoRTH, 2016) highlighting the categories considered for this analysis.

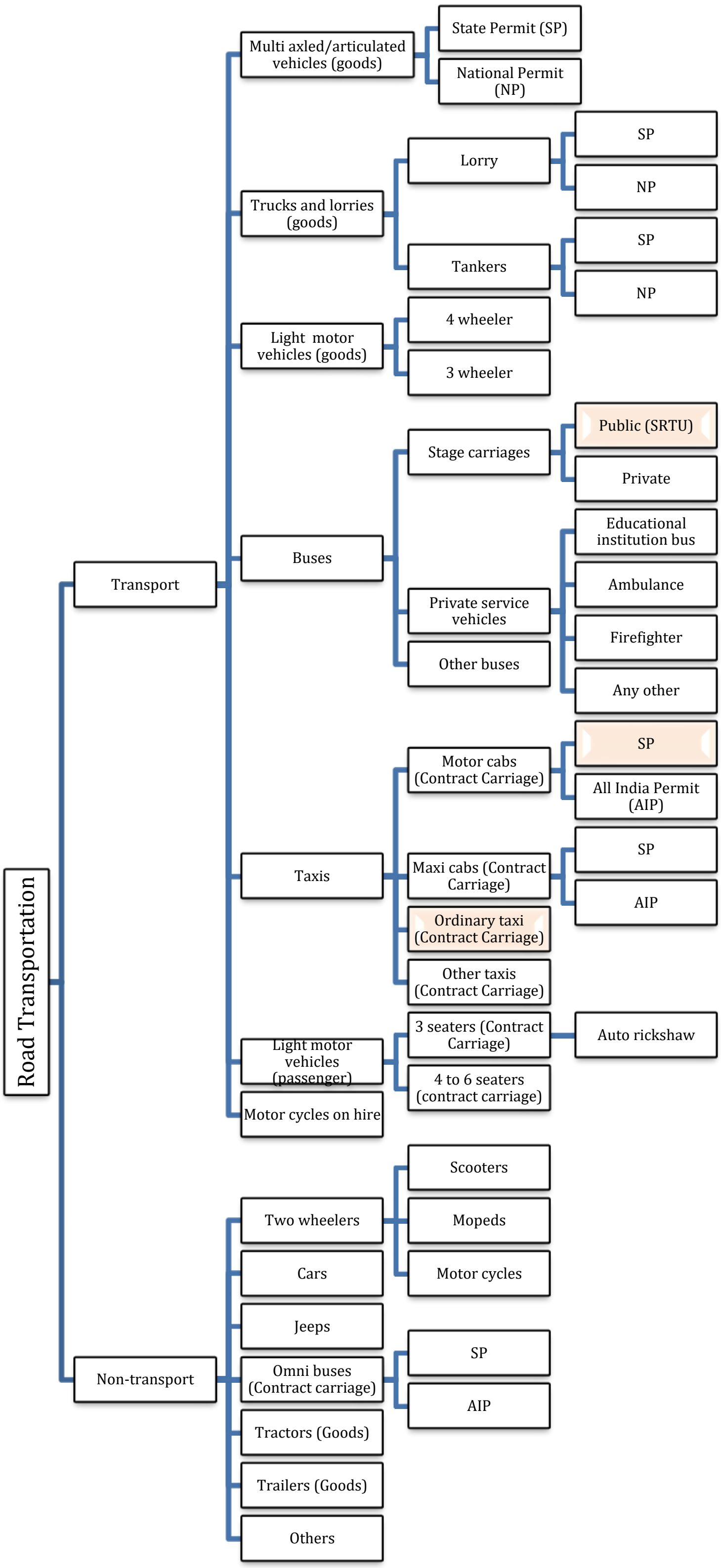

Figure 21: Classification of road transportation sector

In this study, the focus is on the vehicles in the public transportation category, specifically buses and 4W taxis. Further, we limit the categories of interest, based on the classification and the availability of vehicle travel and specification data (considering only intra-city transportation). Buses are limited to those run by public STUs. Taxis are limited to those mentioned in the 'Ordinary taxi' and 'Motor cabs with state permit' categories. We assume that the EV support infrastructure for charging is already established. A listing of the segment under consideration (considering data as on March 31, 2015) is as follows:

- Total number of registered vehicles: approximately *210 million*
- Number of registered 4 wheelers: ~ *28.61 million* (13.62 % of total vehicles)
    - Number of ordinary taxis: ~ *0.27 million* (0.96 % of 4W segment and 0.13% of total vehicles)
    - Number of motor cabs with state permit: ~ *0.62 million* (2.15 % of 4W segment and 0.29 % of total vehicles)
- Number of registered buses: ~ *1.97 million* (0.94% of the total vehicles)
    - Number of public STU buses: ~ *0.141 million* (7.13 % of buses and 0.07% of total vehicles)

Figure 22 indicates the year wise number of buses.

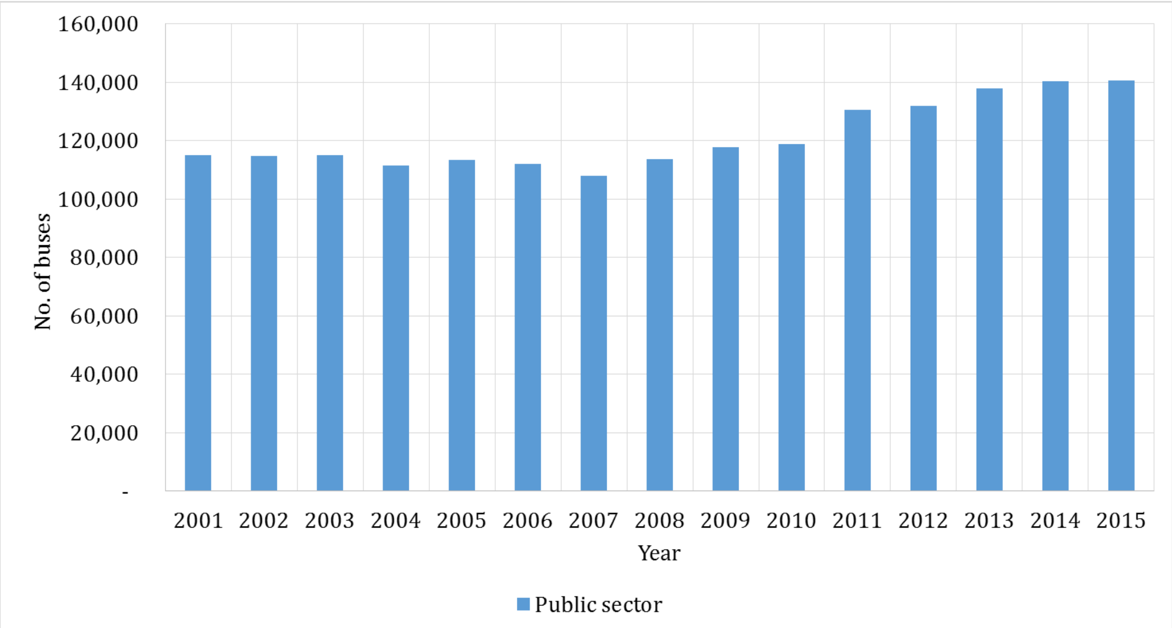

Figure 22: Number of buses in the public sector

We estimate the compounded annual growth Rate (CAGR) from 2005 to 2015 to be 2.17%. We will use this as a reference point.

The total number of vehicles (as on March 31, 2015) under the 'Ordinary taxi' and 'Motor cab with state permit' categories work out to be 0.89 million. Because the year-wise growth of these categories is not provided, we assume the CAGR of this sector to be the same as the reported CAGR (from 2005 to 2015) for the entire four-wheeler sector; that is. around 10.7%.

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