Electric Vehicles as a Solution to Energy Transition
A Case Study of Electric Two-wheelers in Delhi

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Transport is the second major carbon dioxide emitter after the power sector in India. Electric vehicles reduce overall pollution and demand for imported fuels. We surveyed electric two-wheeler owners—mainly salaried class, small business persons, and students travelling up to 10–30 km per day. A survey of 24-hour charging patterns during lean and peak months shows that e2W growth on the grid in the near-to-medium term may not add to peak load, but instead may add revenue for utilities during off-peak times.

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Urban transport in India is growing on the back of economic growth, especially in cities like Delhi. This has given rise to the problems of greenhouse gas (GHG) emissions and air and noise pollution. Early transition to electric mobility is part of the ongoing efforts for greening the grid everywhere. In that, the two-wheeler segment is of particular significance as the first step to private motorised mobility in India, accounting for 84% of all passenger transport vehicles. India has the largest number of two-wheelers in the world at approximately 168 million. It reflects the mobility of the lower and middle classes, essential for national prosperity and satisfaction. Hence, we focus on the electrification of the transport sector and its benefits and challenges, keeping the two-wheeler segment in mind.

Two-wheeler Traffic in India

The share of two-wheeler vehicles out of passenger vehicles in 2019–20 was 84% and 67% for India and Delhi, respectively (Government of India 2021). Car ownership was only 23 per 1,000 in India (International Road Federation 2018), and was 146 per 1,000 in Delhi in 2016 (authors' calculation). This highlights the significance of two-wheelers in the vehicle stock for India in general and also for Delhi. With prosperity, there would be a transition to four-wheelers, but that transition is slow in India and even so, two-wheelers may dominate the markets of developing countries, as also India. Table 1 shows the two-wheelers and cars owned per 1,000 of population in various developed and developing countries.

India has a significantly high number of two-wheelers per 1,000 persons compared to other countries. India's two-wheeler vehicle ownership went up from 17 per 1,000 in 1992 to 128 per

Table 1: Per '000 Capita Ownership of Two-wheelers (2W) in Select Countries, 2015

Countries	Total 2W Vehicles (in '000s)	2Ws as Share of Total Passenger Vehicles by Road (%)	Ownership per 1,000 People
India* (2018)	1,68,975	84	128
Indonesia	1,05,150	0.86	403
China	68,261	0.30	50
Brazil	25,311	0.32	122
Italy	9,740	0.20	161
United States	8,679	0.07	27
Germany	4,314	0.09	52
South Korea	2,181	0.11	43
United Kingdom	1,248	0.04	19
Kenya**	763	0.52	15
South Africa***	367	0.05	7

Source: International Road Federation (2018), *ICCT (2012), **GIZ (2019), ***Government of South Africa (2019).

1,000 in 2018. While in India the ratio of two-wheelers to four-wheelers is 3:1, globally there are 600 million two-wheelers against 1.4 billion cars, that is, a ratio of 1:2.3, which is in the opposite direction. This means that more work is needed to understand the problems of mobility in developing countries. In developed countries, two-wheelers may be an additional vehicle for daily errands, sports, or recreational activity, but in developing countries, it is the first step to motorised mobility as one climbs the income ladder, that is, from poverty to middle class. It is an upward transition from walking, cycling or taking public transport to private vehicles needed to improve productivity, time-saving, and comfort levels while making a living, fulfilling family needs such as shopping, ferrying family members, availing health and education, and pursuing family leisure activities. With a growing middle class, the ownership is likely to grow, although the wealthier class may gradually opt out and prefer four-wheelers. However, that trend is still not as large as the purchase of the first two-wheelers. Recently, the private sector has also focused on this and a large number of electric two-wheeler (e2w) models are available in the market at increasingly competitive prices.

Two-wheelers are important for local and global emission reduction strategies for India. Several policies and measures are underway, among which promotion of electric vehicles is critical. We present a case study of Delhi, where e2w has operated since 2016, which presents an alternative for other cities that suffer from the same malaise. Further, how this transition is taking place needs to be observed from its initial stages. As motorised two-wheelers are unique mainly to developing countries, much of the literature focuses on four-wheelers. What are the difficulties of e2w adopters, their preferences, and the electricity charging demand and load imposed on the grid? What are the social, economic, and technological factors driving e2w usage?

In addition to vehicle owners, different bodies such as manufacturers, electricity providers, and urban planners would have to come together to enable seamless and efficient use of their electric vehicles by owners. The data or vehicle information relevant to and needed by each of the above may be obtained through a survey. For auto manufacturers, the income bracket of buyers, professions, range (distance travelled per full battery charge), purpose of travel, daily distance travelled, and charging behaviour; for urban planners, accommodating charging and parking facilities; for the power sector, how and how much electricity to be provided and how to control the load judging from current behaviour by different pricing policies for sharing the load. Currently, India is in the nascent stages with few consumers who are dynamic and trendsetters, and their numbers are expected to explode soon. We have used the responses from a semi-structured survey to conclude the user behaviour of e2w owners and further insights into the e2w market.

Literature Review

In recent times, there have been several studies on electric vehicles in India. Bansal et al (2021) evaluate the valuation of fuel economy and future fuel costs for Indian consumers while purchasing a two-wheeler, using survey data from more than 8,000 respondents across India. The results show that a high value is attached to future fuel cost savings for respondents. Cherry and Cervero (2007) discuss the reasons behind electric vehicle usage, the users, and the factors that influence travel by electric bikes, based on surveys of two-wheeled vehicle users in Chinese cities, Kunming and Shanghai. The results suggest that electric vehicles can be considered an affordable and higher-quality mobility alternative to public transport. They quantified the safety and environmental impacts of e2ws but found that lead-acid battery pollution has increased in China. On similar lines, Hardt and Bogenberger (2019) evaluate the usage and attitude towards e-scooters in Germany for 38 subjects with six vehicles, using travel diaries and pre- and post-surveys. The results show that e-scooters are majorly used for daily trips and sufficient charging infrastructure is provided for these vehicles. Filippini et al (2021) studied the effects of informational nudges on their stated choice of buying an electric motorcycle, using novel data collected from 2,000 potential motorcycle buyers in Kathmandu, Nepal. The results show that informational nudges positively impact the stated choice of consumers.

Fyhri and Fearnley (2015) discuss the usage of e-bikes in comparison to bicycles in Norway. Using a stated preference survey of households in Hanoi, Vietnam, Jones et al (2013) evaluated the effects of incentives and technology on the adoption of electric motorcycles. The results show that adoption is positively affected by economic incentives and technological improvements. Wei et al (2013) evaluate the travel characteristics of over-standard electric bikes using the revealed preference survey in Shanghai, China. The results suggest that public transport and bicycles are strong competitors of standard electric bicycles. Weiss et al (2015) discuss the environmental, economic, and social performance of e2ws in Europe, suggesting that the latter will substitute conventional two-wheelers in the European automobile market, leading to decreased pollution and impacting electricity generation outside of urban areas. Eccarius and Lu (2020) investigate the factors influencing university students to opt for electric scooters on a shared basis in Taiwan, using data collected from survey responses of 471 participants. The results show that the low preference of university students is because of their lifestyle, mobility needs, and lack of perceived compatibility with personal values. Majumdar et al (2016) discuss the performance of e2ws, based on their running conditions in traffic in urban areas and compare it with their conventional internal combustion engines' counterpart using primary surveys in Kolkata. The results showed that the specific energy consumption of e2ws is significantly lower in comparison to conventional two-wheelers.

Research Design

We carried out a survey for a sample of 122 respondents who owned e2ws between August and September 2020, with the recall or reference period being February 2020 (pre-COVID-19). The sample of owners was chosen randomly and contacted for an interview. Those who agreed to be interviewed were

Figure 1: Monthly Expenditure Profile of Respondents

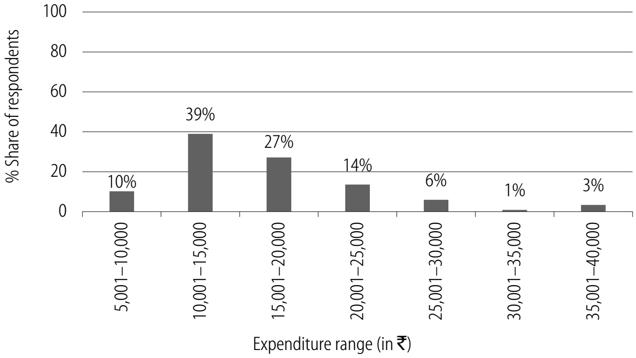


Figure 2: Shift in Purchase Behaviour, 2016–20

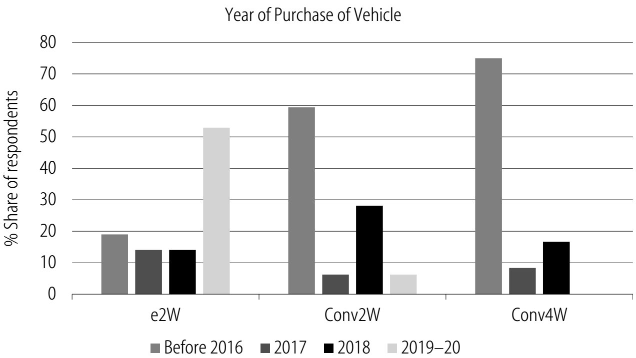
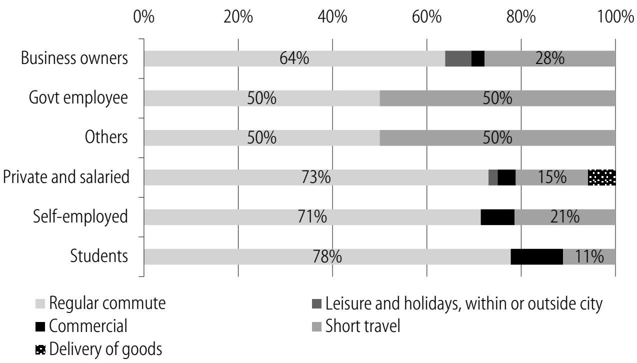


Figure 3: Purpose of Using e2W, by Profession



approached for the survey. The survey respondents were spread across Delhi city and composed of individuals of varying ages, genders, professions, educational backgrounds, and monthly expenditures (Table 2). The survey responses are analysed for social and economic profile, ownership pattern (number and type of other vehicles owned), usage and distance travelled, charging pattern (when, how, and where), technological parameters associated with charging, consumer satisfaction, and factors determining consumer decision to purchase e2ws. A detailed explanation of the survey sample choice is discussed in Annexure A (p 137).

In the survey sample, 91% of respondents are male and 9% female. In terms of their occupation, 43.3% of the respondents are in the private sector and salaried, 30% are business owners and the rest 26.7% are government employees, self-employed, students, and others. The share of graduates was 39.2% followed by those with education at senior secondary level at 26.7%, secondary level 12.5%, pre-secondary level 10.8%, and the rest accounted for postgraduates and undergraduates. The maximum proportion of respondents of around 43% belong to the age group of 25–40 years.

Respondent Preferences

Figure 1 shows that the average monthly expenditure range for respondents lies between ₹7,000 and ₹40,000, after which they may go for four-wheelers. Nearly 39% of respondents lie in the ₹10,000–₹15,000 range followed by 27% in the ₹15,000–₹20,000 range.

It can be seen from Table 3 that 66% of respondents own only one e2w whereas 34% own an e2w in addition to a second or third vehicle that may be a conventional two- and/or four-wheeler. Among the respondents who own a second or third vehicle, 47% own a petrol two-wheeler, followed by 29% who own an e2w, while 24% own petrol four-wheelers as the second or third vehicle. This implies that people opting for a second and those already owning a two-wheeler or car have a high chance of possessing e2ws as their second or third vehicle.

As shown in Figure 2, nearly 50% of the surveyed e2ws were purchased in 2019–20 and the majority of the conventional two- and four-wheeler vehicles were purchased before 2016, implying an increase in the preference for e2ws in recent times. The survey shows that 50% of respondents who are first-time buyers (in this case owning only one vehicle—the e2w) are private and salaried professionals with 25% also having an additional conventional two-wheeler. Among the remaining who purchased e2ws as their second or third vehicle and own more than one vehicle, 19% are business owners who own a conventional two- and/or four-wheeler apart from an e2w.

In terms of vehicle usage, according to survey responses, government employees work for five days a week, salaried and self-employed for six days, and business owners work for seven days. Figure 3 shows that the regular commute followed by short travel is the main purpose of using e2ws across professions. Government employees and other category professions

Table 2: Profile of Respondents

Respondent Profession	Share (%)	Educational Qualification	Share (%)
Private and salaried	43	Postgraduate	9
Business owners	30	Graduate	39
Self-employed	11	Undergraduate	2
Students	8	Senior secondary	27
Government employee	7	Secondary	13
Others—priests	2	Pre-secondary	11
Environmental Awareness	Share	Age Group	Share
Air pollution	99	18–24	26
Water pollution	29	25–39	43
Noise pollution	15	40–55	28
Climate change	7	56+	4

Source: IRADe survey.

Table 3: Vehicle Ownership by Family and Fuel Type (%)

No of vehicles owned by family	
1 (only e2W)	66
>1 (e2W + others)	34
Second vehicle ownership by fuel type	
Electric two-wheelers	29
Petrol two-wheelers	47
Petrol four-wheelers	24

Others include conventional two- and/or four-wheelers.

use e2ws for short travel and few respondents among business owners and private and salaried categories use e2ws for leisure and holiday travel too. This shows that users generally prefer e2ws for travelling fixed, known and small distances. As our intention is to use the results for implications of the electricity load on the grid due to electric vehicle charging, we capture the behaviour on working and non-working days. We further investigate this by analysing the distance travelled using e2ws by respondents of various professions.

As shown in Table 4, the majority of e2w owners use their e2ws or conventional two- and four-wheelers for short-distance travel of 10–30 kilometres (km) per day. This distance can be handled by a one-time charge. A majority of them do not use public transport. Only 28% of respondents on working days and 25% on non-working days reported using public transport, that too for travelling short distances of 1–10 km. This reconfirms that e2w adopters in Delhi are people whose travel requirements are mostly for regular and short-distance travel. Table 4 shows that 55% and 82% of e2w owners who also have conventional two-wheelers do not use the latter on working and non-working days. Similarly, 82% and 84% of e2w owners who also have conventional four-wheelers do not use the latter on working and non-working days. This implies that after purchasing and using their e2ws, they do not use their conventional two- or four-wheelers and hence a policy of buyback of the latter in exchange of e2ws may be very effective.

The average distance travelled by public transport, conventional four- and two-wheelers, and e2ws are 9 km, 41 km, 29 km and 22 km respectively on a working day and 10 km, 51 km, 22 km and 11 km respectively on a non-working day.

Table 4: Daily Distance Travelled (km) by Electric, Conventional Two- and Four-wheeler, and Public Transport on Working and Non-working Days (%)

		0	0–10	11–20	21–30	31–40	41 and Above
e2W	Working day	1	28	31	23	9	8
	Non-working day	43	42	10	3	2	2
Conventional two-wheeler	Working day	82	6	6	3	–	3
	Non-working day	55	6	15	6	9	8
Conventional four-wheeler	Working day	82	–	8	2	4	4
	Non-working day	84	2	2	4	–	8
Public transport	Working day	70	28	2	0	–	–
	Non-working day	66	25	7	2	–	–

Table 5: Consumer Opinion and Preferences of Early Buyers (%)

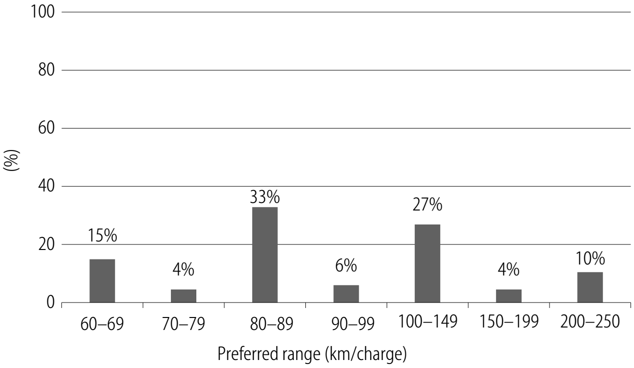
Importance of Factors to Early Buyers While Purchasing e2Ws

Likert	Neutral	Important	Very Important
Capital cost	–	10	90
Range	2	5	93
Charging time	2	9	88
Operating and maintenance cost	1	5	94
Availability of variants	3	24	73
Availability of public charging	5	20	73
Performance of electric vehicles versus conventional	4	17	79
High resale value	6	32	61
Government policies	–	3	97
High petrol price	1	9	90
Emission/environment factors	1	4	95

Satisfaction of Respondents for Various Factors

Likert	Not Satisfied	Somewhat Satisfied	Neutral	Satisfied	Very Satisifed
Range	5	9	8	34	44
Charging cost	1	1	3	2	94
Charging time	4	9	6	30	51
Availability of charging infra	56	2	33	3	7
Waiting time at public charging stations	–	89	2	7	3
Quality of aftersales service	1	4	4	13	78
Satisfaction of consumers					
Satisfaction level	1	1	10	40	48

Figure 4: Percentage Share of Preferred Range Classes



Consumer Considerations

In terms of awareness of environmental issues, almost all the respondents were found to be aware of air pollution as an environmental issue: 29% are aware of water pollution, 15% of noise pollution, but only 7% of climate change. In terms of their knowledge of electric vehicles, the respondents were aware of their environmental benefits.

More than 90% of respondents ranked all the factors identified by the survey (Table 5) as (very) important for purchasing an e2w. Capital cost, range, operating and maintenance cost, government policies, high petrol price, and emission/environment were factors considered very important by at least 90% of respondents while the availability of variants and of public charging, the performance of electric vehicles vis-à-vis conventional, and high resale values were factors considered less important by the respondents.

The satisfaction level for the current status of range is 44%, charging time 51%, and waiting time only 3%. This is a message to manufacturers, whereas availability of charging infrastructure is to be addressed by planners and is a matter of public policy. These are the areas of concern to which future focus should turn. The e2ws are in the categories of moped, scooter, and motorcycle. The average range of scooters from the survey is 54 km per charge and the motorcycle is 104 km per charge. No mopeds are being used by the respondents in the survey. Based on their usage of e2ws, respondents provided the preferred range as shown in Figure 4.

Among the respondents who made suggestions on preferred waiting times at charging stations, 58% preferred a waiting time of one hour followed by 36% preferring two hours. Other

Figure 5: Frequency of Charging per Week

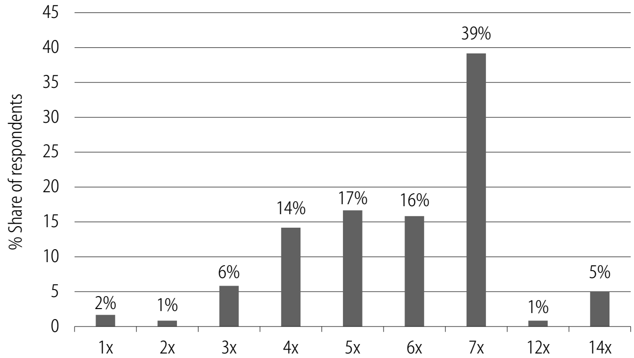
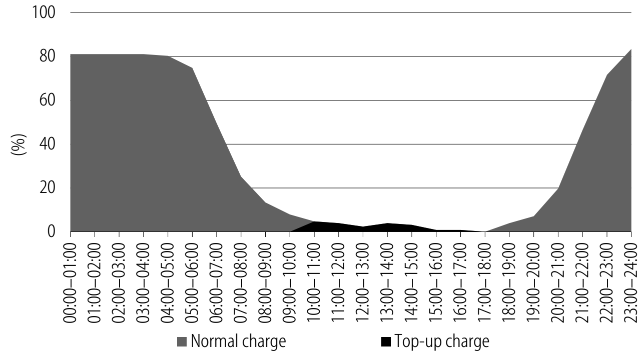


Figure 6: Estimated Proportion of e2W Charging at Each Hour on a Working Day



suggestions by respondents include the availability of charging infrastructure every 2–3 km or 10 km, every petrol pump and/or major commercial place, and preference for service centres all around. Given the current scarcity of infrastructure, one can say that the early adopters have factored this into their decision as they have an option of charging it overnight or at the office. However, for the next level of expansion, availability of fast charging will reduce the waiting time and improved charging infrastructure can increase the usage of electric vehicles. Overall, 88% e2W users are satisfied with the performance of the vehicle while only a small and limited share of consumers are dissatisfied.

Parking and Charging

The availability of parking and proximity of charging facility is an important aspect of e2W mobility. For early buyers, slow or regular charging is an essential requirement for electric vehicles, especially during the night or idle time. Survey responses show that 43% of early adopters have a garage parking facility, 31% use public or on-street parking, 26% park in society spaces, and 1% park in other available spaces for charging during this time. The survey responses showed a lack of awareness and availability of public- and office-charging facilities. Only 9% of respondents had charging options available at their office and only 6% were aware of the public charging facilities near their homes and offices. This is despite 50% of respondents having public charging facilities within 5 km of their homes and 60%, within 5 km of their offices.

The average monthly charging cost for all respondents with e2Ws is estimated to be ₹64. Table 6 also shows that more than 90% of respondents charge at their homes and that office and shop charging are almost negligible. Currently, no respondents were found to be using public charging because the early adopters knew the range limitations at the time of buying and thus mostly use it for short distances.

Table 6: Location and Cost Preference for Charging

	Location of Charging (% of Respondents)	Average Cost per Charge (₹)
Home	91	13
Office	5	5
Shop	4	15

Figure 5 shows the number of times respondents charged their e2Ws per week, with 39% charging their e2Ws seven times a week, that is, once a day. It also means that 94% of respondents do not charge their e2Ws more than once a day due to short-distance travels.

The regular charging time on weekdays and weekends is from 7 pm to 8 am. Survey respondents did not explicitly mention top-up charging. The respondents were asked for the number of instances of charging on their last working and non-working day and on each instance of charging, the type of charging (regular or top-up), the plug-in and plug-out time, the plug-in and plug-out state of charge (SoC) because, depending on the already existing charge in the batteries, the time taken to charge may vary.

Table 7 provides the class-wise frequency distribution table for plug-in SoC and the corresponding class-wise average SoC, average battery charged, and average time taken from sample responses for weekdays and weekends. The average plug-in SoC during full charge for e2Ws in a working day is 24%, and for non-working days, 34%.

Of the total responses, 32% respondents have SoC in the 10%–19% range followed by 31% in the 20%–29% range on a working day. On non-working days, 27% of respondents have SoC in the 50%–59% range followed by 25% having SoC in the range of 40%–49% range while plugging in for charging their vehicles.

The plug-in and plug-out time for each charging by the respondents on working and non-working days were used to compute the proportion of vehicles charging at each hour of the representative weekday and weekend as shown in Figure 6 for working days and Figure 7 for non-working days. The transport use of e2Ws is lower over the weekends as regular commute to office, a major purpose of using e2Ws as shown above, is not needed on weekends. Therefore, the e2W on weekends are

Table 7: Weekend and Weekday Charging-related Battery Parameters

SoC Plug-in Weekday (%)	Average SoC (%)	Remaining Battery Charged (%)	Average Time Taken (hrs)	Share of Respondents (%)
10–19	12	87	9:57	32
20–29	20	79	8:41	31
30–39	30	68	7:46	17
40–49	40	57	8:05	13
50–59	50	44	3:06	4
60–69	60	33	3:40	3
Average	24	74	8:38	100
Weekend				
10–19	11	89	9:17	21
20–29	20	78	10:05	11
30–39	30	70	7:25	13
40–49	40	58	8:51	25
50–59	50	49	6:04	27
60–69	60	40	3:30	4
Average	34	65	7:57	100

Figure 7: Estimated Proportion of e2W Charging at Each Hour on Non-working Day

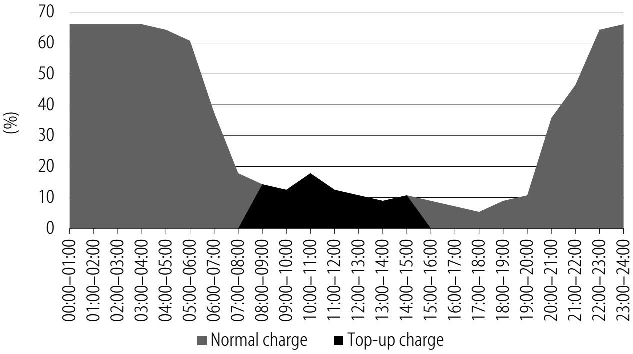


Figure 8: Share of Electric Vehicle Load in 2030 in Total Load for Peak Month of June for Weekdays and Weekends

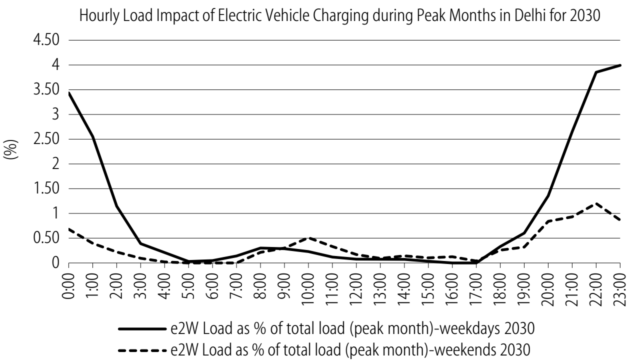
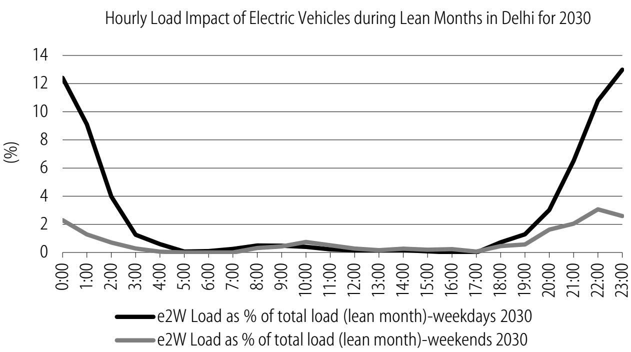


Figure 9: Share of Electric Vehicle Load in 2030 in Total Load for Lean Months of June for Weekdays and December for Weekends



used for other purposes resulting in different charging profiles on weekdays and weekends for e2ws.

Impact on Grid

Given the above consumer preferences and charging patterns, what would be the impact on the grid, due to larger-scale adoption? When should more electricity for charging be planned? We address this by estimating the hourly impact on grid due to e2w charging in Delhi for 2030. To calculate the electricity load at each hour of the day, vehicle type-wise (segregated into groups and assigned sample share) technological characteristics like battery capacity in kilowatt-hours, time taken to charge from 0% to 100% (in hours), time of plug-in and plug-out, soc at the time of plug-in (for weekdays and weekends), and total count of vehicles surveyed were collected from the survey sample. No vehicle in the survey was with more than 70% plug-in soc. Common plug-out time is assumed for identical vehicles with similar soc and plug-in time, and connected with the same rate of charging. If the charging rate is explicitly not available, then using the above data and percentage of individual vehicle type in total vehicle count, the charging rate is calculated as Charging rate = {(Battery capacity)/(Time taken to fully charge from 0% to 100%)} for various soc values. Using the calculated charging rate, electricity load on the grid is calculated using the following equation:

$$\sum_{n=1}^{24}(\text{Grid})\text{EV Load} = \sum_{n=1}^{24}[\text{SoC} \times \text{N charged} \times \beta]$$

where EV = electric vehicle, n = hour of the day, $(SoC)_n$ = state of charge of the vehicle in n^{th} *hour* = $[(SoC)_{n-1} + \frac{\beta}{\omega}]$, where, β = charging rate, and ω = battery capacity, N = number of vehicles charged.

Based on the authors' calculations, the estimated count of e2ws in 2019–20 was 3,346, which is 0.1% of the total estimated two-wheeler vehicle stock in Delhi but is projected to climb up to 34% with 1.5 million purchased units. It is assumed that all the e2ws are charged on weekdays and only 45.51% of the vehicle count is charged over weekends for 2019–20 and 2030 based on survey results. Using the above e2w vehicle count and analysing the impact of charging, the hourly load for weekdays and weekends out of the total hourly demand in peak and lean months load is found to be insignificant for 2019–20 as the count of estimated e2ws is only 0.10% of the total vehicle count in Delhi. However, the impact is significant for 2030 due to the high share of 34% of e2ws in the total two-wheeler count. The impact of e2w hourly load on weekdays and weekends out of the total peak and lean month load for 2030 is significant and shown in Figures 8 and 9. As can be observed from Figure 8, in a typical peak month weekday, hourly load can be 4% of the total hourly load for the time slots of 10 am–11 am. The additional demand (7 pm–10 pm) can be problematic as it would impose a burden on the grid. However, hourly load is close to 1% between 6 am and 5 pm, which does not pose much problem during daytime, except at mid-morning for a top-up charge. However, in a typical lean month weekday, the hourly load can be 13% of the total load for the time slot of 11 am–12 pm and as low as 0% for the time slot of 4 pm–5 pm and 5 pm–6 pm. For a typical lean month weekend, the hourly load can be 3% of the total weekend hourly peak month load for 10 pm–11 pm and as low as 0% for 5 am–6 am, 6 am–7 am, and 7 am–8 am. Thus, it can be stated that the impact of e2w load on the grid on weekdays and weekends for peak and lean months would not only be not problematic up to the year 2030 but will add revenues during off-peak times. However, the extra load during 7 pm–10 pm should be avoided, which is critical for lean months, when the demand for power is less.

Conclusions and Policy Implications

The electrification of vehicles can reduce air pollution, GHG emissions, and imports of petroleum products. The Government of India aims to have electric vehicles as 35% of all total vehicles by 2030 (*Economic Times* 2024). Two-wheelers are a large part of vehicles in Delhi. The adoption of e2ws is rapid as they can charge them at home or the workplace and their daily use is limited. What is the customer profile of e2ws and how would their charging patterns impact power supply? In order to encourage electric mobility of two-wheelers, relevant information has to be provided to auto manufacturers, electricity providers, and urban planners. We carried out a survey of e2w owners in Delhi to understand who they are, how far they drive, where they park, and when and where they charge. The sample respondents are among the early buyers of e2ws. Therefore, conclusions would have to be drawn with caution. For example, respondents have already chosen a variant and now no longer care for more variants or they have bought it knowing that a special charging infrastructure does not yet exist. New variants introduced may encourage more new buyers, increasing electric vehicle penetration and their impact on the grid. Keeping these possibilities in mind, the summary findings and policy conclusions for e2ws are as follows.

Buyer's profile: Most early adopters of e2ws in Delhi belong to relatively lower-middle-income households with a monthly household expenditure range of ₹5,000–₹20,000. Higher income brackets may subsequently shift to four-wheelers. They are graduates or senior secondary educated and in the working-age group of 25–40 years. Among first-time vehicle buyers, salaried individuals and the second- or third-time buyers, business owners are among the biggest early adopters of e2ws in Delhi.

Travel use patterns: The average range of electric scooters in survey was 54 km per charge and for motorcycles, it was 104 km per charge. Most early adopters of e2ws across professional categories use it for regular commutes and short-distance travel. They have replaced their previously owned conventional vehicles with e2ws for work-related travels. They travel between 1 km and 30 km per day, the estimated daily average being 22 km on working days and 11 km on non-working days. Nearly 55% of respondents who own a conventional two-wheeler along with an e2w, do not use their conventional vehicles on working days. Their daily vehicle kilometres using their previously owned conventional two- and four-wheeler were estimated to be 29 km and 41 km respectively on working days and 22 km and 51 km on non-working days.

Purchase and usage of e2Ws: Capital cost, range, operation and maintenance cost, government policies, high petrol prices, and environmental impact as factors are considered very important by 90% respondents. While availability of variants and public charging, performance vis-à-vis conventional two-wheelers, and high resale value are factors considered less important in their decision to purchase e2ws. Most respondents were satisfied with their e2ws, however, respondents expressed less satisfaction with the existing range, charging time, availability of charging infrastructure and waiting time at public charging stations. About 62% of respondents suggested improvements in the range, charging infrastructure, cost of charging, availability of fast charging, and better after-sales service quality. Nearly 39% of those who suggested improvements in the range, preferred a range of 80–100 km/charge. The preferred waiting time was one hour for 36% of respondents who suggested lower waiting times. Other suggestions include public charging stations every 2–3 km, or within every 10 km, or at every petrol pump and major commercial place, and free regular servicing in the first year and improved service quality with service centres all around.

Availability of charging facilities: Most of the e2w owners, who are early adopters, have access to basic parking facilities at home and hence, 90% of the respondents charged from home. Only 9% had charging options at their office and 94% were not aware of public charging facilities near their home or office. Among those respondents who are aware of public charging stations, only 60% and 50% have a public charging station within 5 km of their home and office respectively. None of the respondents visited a public charging station and so were unaware of the waiting times there.

Charging behaviour: Among the survey respondents, 39% charge their e2ws once a day, and 55% charge less than once a day implying an average charging frequency of at the most once a day. Regular charging requires around 7 hours to 8 hours and takes place in the time slot of 7 pm to 8 am. Only 9% and 16% of the respondents did top-up charging on a weekday and weekend respectively. During regular charging, 63% of respondents had 10% to 30% plug-in soc on working days and 52% had 40% to 60% plug-in soc on non-working days.

Impact of e2W hourly load on the grid: Assuming a 35% share of total two-wheelers by 2030, the impact of charging by e2ws on the total hourly load of the evening peak hours on weekdays and weekends is estimated to be around 4% and 1% respectively in the peak months and 13% and 3% respectively in the lean months. The increase in load during early morning hours will increase electricity distribution company (DISCOM) revenues.

This survey provides important information to auto manufacturers about the expectations for battery size, range, charging time, the demographic profile of buyers, their usage patterns and purpose of use. To urban planners, the survey identifies factors like environmental awareness and how to facilitate e2w usage by providing parking facilities and charging infrastructure. To the electric utility planners, the survey provides information about their charging needs and hourly electricity demand on the grid, and provision of electricity. It reassures that a sudden rush to electric vehicles may not jeopardise electricity supply and may even be helpful to increase the off-peak demand and capacity utilisation.

Our survey also covered other passenger vehicles, such as electric three- and four-wheelers (private and taxis), which will be published separately. We believe this to be the first comprehensive primary survey of e2ws that can throw some light on many decisions for various stakeholders. It provides a baseline survey that could be repeated to check for changes in consumer profiles over time or in other cities to understand the impact on the grid due to electric vehicle charging patterns.

With consumer awareness and availability of timers and appropriate time-of-use prices, charging patterns can be shifted to off-peak hours without the need for additional power capacity and bring more revenues for DISCOMs. These conclusions should be reviewed after a few years to assess changes in demand and supply structures. Over the next five to 10 years, the electric vehicle growth can be managed, provided prudent planning measures to avoid 7 pm to 10 pm charging time slots begin soon.

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Annexure A: Sample Size of Surveys and Reliability

The survey undertaken in this study covered 120 current private users of e2W. Compared to usual travel surveys, the number of sample points included looks low. Although, ideally, a larger sample would have reduced sample variance and improved precision, at the time of the project, the market penetration of electric vehicles was very low and so it was decided to conduct small surveys.

The smaller sample size neither makes the estimates unbiased nor less precise. The survey data is used to compute various average values of variables and ratios of interest. Firstly, the computed sample averages and proportions are unbiased estimates of the actual population averages and proportions. For theoretical proof, see Chapter 2, theorem 2.1 in Cochran (1999), which states that the sample mean is an unbiased estimate of the population mean. This is independent of the sample and population size. The variance of the estimated sample average $\underline{y}$, denoted as $V(\underline{y})$, and estimated sample proportion p (possessing a particular characteristic) as v(p) is given by below equation,

$$V(\underline{y}) = \frac{S^2}{n}\cdot\frac{(N-n)}{N} \quad \text{... (A.1)}$$

where S^2 is the variance of the population distribution, N is the population size, and n is the sample size; see Theorem 2.2 in Cochran (1999). The equation below gives the variance of sample proportion of characteristic of interest,

$$v(p) = \frac{(N-n)}{(n-1)N}pq \quad \text{... (A.2)}$$

where p is the estimated sample proportion of people having a characteristic of interest in the total sample and $q=1-p$. See Theorem 3.3 in Cochran (1999).

The target population for the survey in this study is e2W users for which the numbers are very low compared to the whole vehicle stock. Hence, the population for the survey in consideration is finite.

The factor, $\frac{(N-n)}{N}$, is called the finite population correction (FPC) which tends to one as population size N tends to infinity. Thus, quoting Cochran (1999: 24), Section 2.6 "provided that the sampling fraction n/N remains low, these factors are close to unity, and the size of the population as such has no direct effect on the standard errors of the sample mean." Cochran further adds, "In practice the FPC can be ignored whenever the sampling fraction does not exceed 5% and for many purposes even if it is as high as 10%. The effect of ignoring the correction is to overestimate the standard error of the estimate $\bar{y}$" (p 25).

For an estimate of the size of population, we consider the total registered e2Ws in Delhi and also estimated total on-road vehicle stock of e2Ws in Delhi using survival rates for two-wheelers. This is shown in Table A.1 below.

The FPC for early adopters of e2Ws is shown as the percentage of the total registered stock and on road vehicle stock of two-wheelers. The FPC for e2Ws is 6.9% and 5.7% based on registered vehicle stock or on road vehicle stock respectively. Therefore, even though the target population for the surveys is low, the FPC based on the survey is below 10% and therefore, the variance of the estimated sample average is as shown below.

$$V(\underline{y}) = \frac{S^2}{n} \quad \text{... (A.3)}$$

And the estimated sample proportion "p" is as shown below.

$$v(p) = \frac{1}{(n-1)}pq \quad \text{... (A.4)}$$

Thus, sample variance depends only on sample size and not on the size of the population under consideration. In statistics, a sample of size $n>30$ is generally considered to be a large sample and since the sample size is 123 which is greater than 100, we can consider the sample variances as a close approximation of the population variances and the sample estimates as reliable.

Table A1: Estimated Population Size of e2W in Delhi, 2019–20

	2019–20	Total Registered from 2015–16 to 2019–20
Motorcycle/scooter	956	1,743
Motorcycle/scooter-with side car	0	0
Mobile workshop	0	0
Moped	9	47
Total registered vehicles	965	1,790
Total estimated on-road vehicle stock	2,185	
Sample size as % (FPC) of total for electric vehicle early adopters based on total registered vehicles of e2Ws	6.7%	
Sample size as % (FPC) of total for EV early adopters based on total on-road vehicle stock of e2Ws	5.5%	

Source: Vahan Database for Delhi, viewed on 21 January 2022.