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Battery capacity needed to power electric vehicles in India from 2020 to 2035

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Introduction

India has been heavily reliant on the international market to meet its electric vehicle (EV) component needs, especially battery cells. To change this, NITI Aayog, the Government of India's (GoI) premier policy think tank, recently initiated the National Programme on Advance Chemistry Cell (ACC) Battery Storage.[1] It is meant to support the domestic manufacturing of 50 gigawatt hours (GWh) of ACCs. NITI Aayog describes ACCs as battery cells with new generation, advanced storage technologies that can store electric energy as chemical energy and convert it back to electric energy when required. The plan proposes a production-linked subsidy ranging from US$27 per kilowatt hour (kWh) to US$56/kWh for manufacturers who set up production units with a capacity of at least 5 GWh.[2] Also proposed is an increase of the import tax on battery cells from 5% to 15% after 2022.[3]

These are important steps toward realizing the goals of India's National Mission on Transformative Mobility and Battery Storage, established in March 2019.[4] The aim of this mission is to formulate and launch Phased Manufacturing Programmes (PMP) that (1) promote localized production across the entire value chain for EVs and EV components and (2) focus on raw materials, electrochemistry, and end-of-life treatment of cells, modules, and battery packs for EVs.

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1 Government of India, NITI Aayog, "National Programme on Advance Chemistry Cell (ACC) Battery Storage: Draft Model Bid Documents," November 11, 2020. https://niti.gov.in/sites/default/files/2020-11/Model-Bid-Documents-ACC.pdf

2 US$1 = 74 Indian rupees was used as the exchange rate for this paper

3 Neha Arora and Aftab Ahmed, "Exclusive: India plans $4.6 billion in incentives for battery makers in electric vehicle push – document," *Reuters*, September 25, 2020, https://in.reuters.com/article/us-india-batteries-incentives-exclusive/exclusive-india-plans-4-6-billion-in-incentives-for-battery-makers-in-electric-vehicle-push-document-idINKCN26G1E1

4 Government of India, NITI Aayog, "Notification: National Mission on Transformative Mobility and Battery Storage of NITI Aayog," March 8, 2019. https://www.niti.gov.in/niti/writereaddata/files/new_initiatives/Mission_notification.pdf

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Background

In March 2019, a PMP to promote indigenous manufacturing of all categories of EVs and their components was announced by GoI's Department of Heavy Industry.[5] Subsequently, the eligibility criteria[6] for the national Faster Adoption and Manufacturing of Electric Vehicles (FAME)[7] scheme was revised to require domestic manufacturing of parts for two-wheelers, three-wheelers, passenger cars, and buses, so that all components are locally sourced by April 2021. However, there was no restriction imposed on the sourcing of battery cells and the associated battery management system. EV manufacturers were only required to assemble the battery packs in India. This is reflective of the nascent status of India's battery cell manufacturing industry.

Still, Indian Prime Minister Modi's subsequent call for a self-reliant[8] India has placed new emphasis on promoting local manufacturing, and GoI recently announced a five-year, US$19.7 billion production linked incentive (PLI) scheme for 10 key sectors that includes US$2.4 billion for ACC batteries and US$7.7 billion for automobiles and auto components.[9] Although the current market share of EVs in India is less than 1%[10], India's commitment to the EV30@30 global initiative, which targets a 30% new sales share for EVs by 2030, translates to the addition of about 24 million two-wheelers, 2.9 million three-wheelers, and 5.4 million four-wheelers to its fleet in the next 10 years. Additionally, the electrification of transport is imperative for India to reach its decarbonization goals and improve air quality in its cities.

ICCT's previous research indicated that plug-in hybrid electric cars would not reach upfront cost parity with conventional cars in the foreseeable future.[11] Plug-in hybrid electric cars with significant electric range (80 km) will remain more expensive than conventional cars, and the price advantage of battery electric cars over plug-in hybrid electric cars will grow substantially from about 2024 onward. Based on these findings, we have assumed that, moving forward, all categories of electric vehicles in India will be fully battery electric.[12]

In this work, we estimate the battery manufacturing capacity that will be required for EVs, by year, up to 2035, under two future scenarios. We then discuss what that would mean for the industry's development in India. This rest of this paper is organized as follows. First, we define the two scenarios and outline the data sources and methodology used to forecast EV sales. Next, we describe the steps involved in determining the capacity of EV battery packs in the future. Following that, we estimate the total battery capacity required up to 2035. We then conclude with a summary of our findings and a discussion of the policy implications.

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5 Government of India, Ministry of Heavy Industry and Public Enterprises, "Notification: Phased Manufacturing Programme to promote indigenous manufacturing of electric vehicle, its assemblies/sub-assemblies and parts/sub-parts/inputs to the sub-assemblies thereof," March 6, 2019. https://dhi.nic.in/writereaddata/fame/famedepository/1-pmp.pdf

6 Government of India, Ministry of Heavy Industry and Public Enterprises, "Notification no. 7(02)/2019-NAB. II(Auto) (20307): Phased Manufacturing Programme (PMP) for xEV Parts for eligibility under FAME India Scheme Phase-II –regarding," September 29, 2020. https://www.dhi.nic.in/writereaddata/UploadFile/PMP%2029Spet20.pdf

7 Government of India, Ministry of Heavy Industry and Public Enterprises, "Notification S.O. 1300(E): Scheme for faster adoption and manufacturing of electric vehicles in India – phase II," March 11, 2019. https://dhi.nic.in/writereaddata/UploadFile/DHI_FAMEII_Gazette.pdf.

8 Government of India Press Information Bureau, "PM gives a clarion call for Atmanirbhar Bharat," May 12, 2020, https://pib.gov.in/PressReleseDetail.aspx?PRID=1623391

9 Government of India Press Information Bureau, "Cabinet approves PLI scheme to 10 key sectors for enhancing India's manufacturing capabilities and enhancing exports – Atmanirbhar Bharat," November 11, 2020, https://www.pib.gov.in/PressReleasePage.aspx?PRID=1671912

10 KPMG and CII, *Shifting gears: the evolving electric vehicle landscape in India*, (October 2020), https://assets.kpmg/content/dam/kpmg/in/pdf/2020/10/electric-vehicle-mobility-ev-adoption.pdf

11 Nic Lutsey and Michael Nicholas, *Update on electric vehicle costs in the United States through 2030*, (ICCT: Washington, DC, 2019), https://theicct.org/publications/update-US-2030-electric-vehicle-cost.

12 Some mild-hybrid and plug-in hybrid electric cars will continue to exist in India, but are not analyzed separately in this paper.

Scenarios and sales forecasts

We evaluated two transport electrification scenarios using ICCT's India Emissions Model (IEM)—Ambitious and 30@30.[13] The Ambitious scenario is an optimistically rapid transition to EVs that supports India's air quality goals and its Nationally Determined Contribution (NDC), which seeks to reduce carbon intensity by 33% to 35% by 2030 from 2005 levels. In the 30@30 scenario, 30% of new automotive sales are electric by 2030. Table 1 shows the EV penetration in different vehicle categories in the two scenarios.

Table 1. EV share of new sales under different transport electrification scenarios in the IEM

<table>
<tr><th>Acronym</th><th>Description</th><th>30@30</th><th>Ambitious</th></tr>
<tr><td>2WLS
2WCS
2WHP</td><td>Two-wheelers, low speed
Two-wheelers, commuter segment
Two-wheelers, high performance</td><td>30% by 2030
100% by 2047</td><td>75% by 2030
100% by 2040</td></tr>
<tr><td>3W</td><td>Three-wheelers</td><td>30% by 2030
100% by 2047</td><td>75% by 2030
100% by 2040</td></tr>
<tr><td>PC</td><td>Passenger cars, ≤ 3.5 ton gross vehicle weight rating (GVWR)</td><td colspan="2">30% by 2030
100% by 2047</td></tr>
<tr><td>U&MPV</td><td>Utility and multi-purpose vehicles, ≤ 3.5 ton GVWR</td><td colspan="2">30% by 2030
100% by 2047</td></tr>
<tr><td>BusL</td><td>Light-duty bus, ≤ 7.5 ton GVWR</td><td>30% by 2030
100% by 2047</td><td>28.1% by 2030
100% by 2044</td></tr>
<tr><td>BusM</td><td>Medium-duty bus, > 7.5 ton GVWR</td><td>30% by 2030
100% by 2047</td><td>8.7% by 2030
100% by 2047</td></tr>
<tr><td>BusH</td><td>Heavy-duty bus, > 12 ton GVWR</td><td>30% by 2030
100% by 2047</td><td>8.7% by 2030
100% by 2047</td></tr>
<tr><td>TruckL</td><td>Light-duty truck, ≤ 3.5 ton GVWR</td><td colspan="2">28.1% by 2030
100% by 2044</td></tr>
<tr><td>TruckM</td><td>Medium-duty truck, 3.5 to 12 ton GVWR</td><td colspan="2">10% by 2030
100% by 2060</td></tr>
<tr><td>TruckH</td><td>Heavy-duty single unit and combination trucks, >12 ton GVWR</td><td colspan="2">10% by 2030
100% by 2060</td></tr>
</table>

The IEM forecasts both sales and stock, by year, for all automobiles classified as motor vehicles according to the Automotive Research Association of India's AIS-053 specifications.[14]

According to AIS-053, e-bikes do not qualify as motor vehicles. However, given there are about 100,000 e-bikes on Indian roads, they are incorporated as an additional category in our analysis. E-bikes are low-powered, low-speed, low-performance two-wheelers that do not require a license to operate. Some of these can achieve a top speed of 25 kmph and are powered by motors smaller than 0.25 kW. On the other hand, for EVs categorized under the 2WLS segment, the top speed is between 25 and 45 kmph. Some e-bikes and 2WLS are powered by lead-acid batteries, but for this analysis, we only assessed two-wheelers with lithium-ion batteries. This is because we assume that all EVs in India will transition to lithium-ion batteries in the near future.

E-bikes received a tremendous boost in sales when the FAME scheme was first launched in 2015 and provided substantial purchase subsidies for all kinds of EVs. In April 2019, the eligibility criteria was updated and rendered e-bikes ineligible. Nevertheless, this segment is still riding high on the initial thrust it received from FAME, and we assume this market will continue to grow. We estimated the stock of e-bikes based on sales

13 Gaurav Bansal and Anup Bandivadekar, *India's vehicle emissions control program*, (ICCT: Washington, D.C., 2013), https://theicct.org/publications/indias-vehicle-emissions-control-program.

14 Automotive Research Association of India, "AMENDMENT NO. 7 (08/2018) TO AIS-053: 2005 automotive vehicles -types –terminology", https://hmr.araiindia.com/Control/AIS/1122018124347PMAIS-053_7amds_and_Corri_1.PDF

data available on the Department of Heavy Industry's FAME[15] portal and used a 6% compounded yearly growth rate in sales, which puts the 2035 stock at about 282,000.

The Ministry of Road Transport and Highway's Vahan database tracks the registration of all types of vehicles in India.[16] The database shows that 3,73,000 e-rickshaws were registered by the end of 2019. Although e-rickshaws are required by law to be registered with government agencies, only a small fraction of them actually are, and that makes it challenging to establish the true number of e-rickshaws on the road. Based on historic sales data available at the same data source, we forecasted consistent yearly sales of 1,44,000 e-rickshaws for all future years, which puts the 2035 stock at about 2.6 million.

E-rickshaws are the preferred mode of transport for last-mile connectivity in the northern and western parts of India. E-rickshaws are low efficiency three-wheelers which have an average range of about 80 km on a single charge. They are usually powered by lead-acid batteries, which have a life of 9 to 11 months.[17] However, we only assessed e-rickshaws with lithium-ion batteries, under the assumption that all EVs in India will make the transition to lithium-ion batteries in the near future.

Figure 1 shows the projected annual sales, by year, for the two-wheeler segment in the 30@30 and Ambitious scenarios. Following it, Figure 2 shows the projected annual sales, by year, for all other EV categories in the 30@30 and Ambitious scenarios.

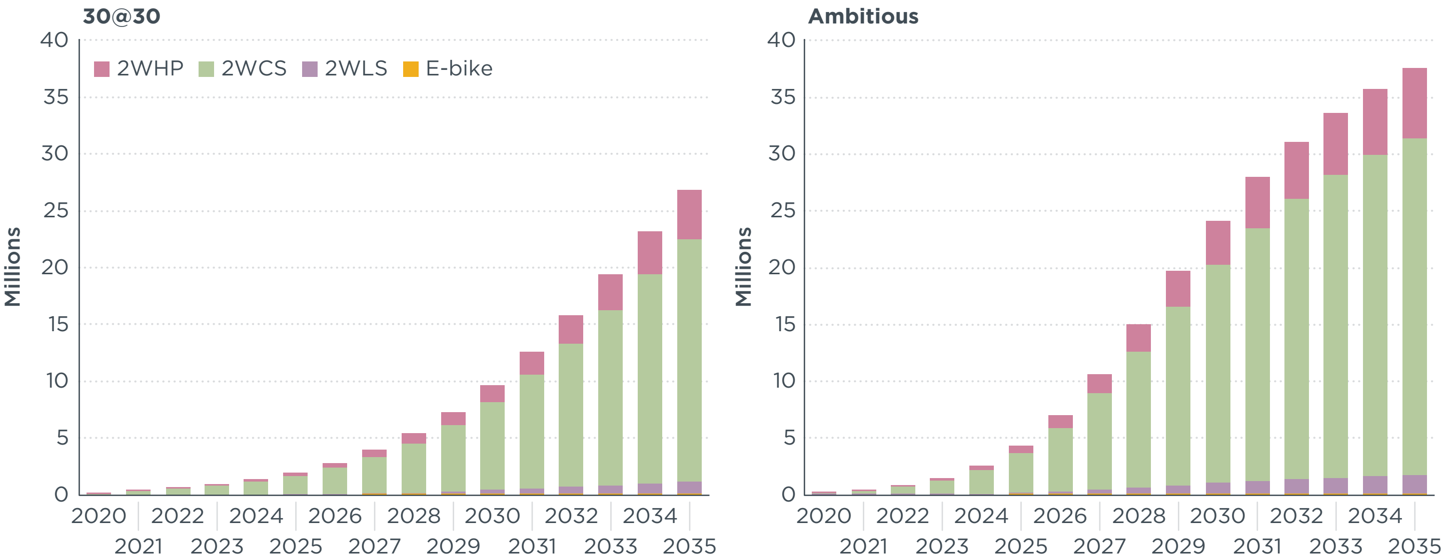

Figure 1. Annual sales projections for electric two-wheelers in the 30@30 (left) and Ambitious (right) scenarios, 2020–2035. *Note:* The share of e-bikes is exceedingly small relative to the others.

15 "Total Number of Vehicles Sold," FAME India Scheme II, Government of India, Department of Heavy Industry. https://fame2.heavyindustry.gov.in

16 Government of India, Ministry of Road Transport and Highways, "Vahan dashboard", accessed September 10, 2020. https://vahan.parivahan.gov.in/vahan4dashboard/

17 ICLEI South Asia, *Handbook: E-rickshaw deployment in Indian cities (Supporting Sustainable Mobility under Smart City Mission)*, (ICLEI South Asia: New Delhi, 2020), https://shaktifoundation.in/wp-content/uploads/2019/07/Handbook-ERickshaw-deployment-in-Indian-Cities.pdf

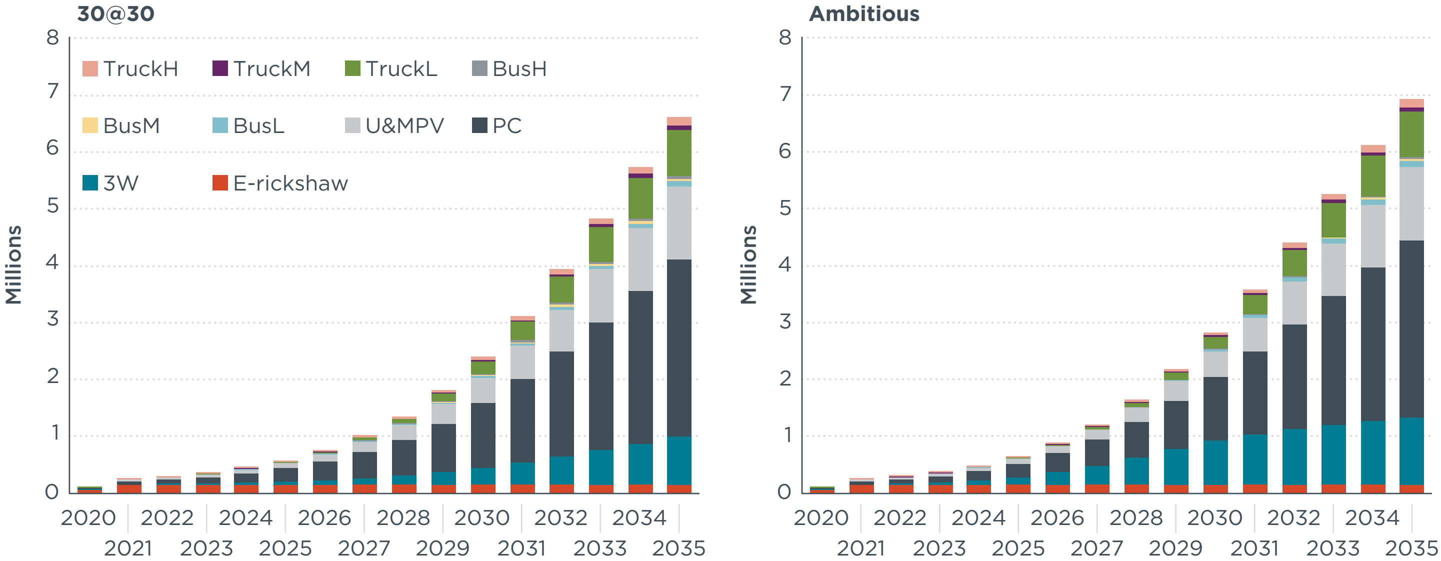

Figure 2. Annual sales projections for EVs other than two-wheelers in the 30@30 (left) and Ambitious (right) scenarios, 2020–2035.

Capacity of battery packs

To estimate the capacity of EV battery packs in the future, we assessed the EVs with advanced cell chemistries that are currently available in the Indian market. The table in the appendix shows the typical values of declared battery capacity, estimated real-world driving range, and the corresponding energy consumption of the EVs we assessed. For the purpose of this study, the manufacturer declared battery capacity is considered to correspond to the usable or net battery capacity.

Examining the currently available EVs revealed that consumer choices are limited or not extant in certain segments. There is no light-duty electric bus available, and only one model each of utility and multipurpose electric vehicle, light-duty electric truck, medium-duty electric truck, and heavy-duty electric truck are currently available. Hence, for these categories, we looked at models available in other countries and referred to literature. Based on this, we assumed representative values of battery capacity and energy consumption for each EV category, and this is shown in Table 2.

Table 2. Typical values of net battery capacity and energy consumption in 2020 for different vehicle categories

Vehicle category	Net battery capacity, kWh	Energy consumption, kWh/km
E-bike	1.2	0.016
2WLS	2.2	0.025
2WCS	3.0	0.030
2WHP	4.6	0.035
E-rickshaw	3.7	0.043
3W	7.4	0.057
PC	40	0.157
U&MPV	49	0.209
BusL	70	0.450
BusM	124	0.840
BusH	300	1.130
TruckL	15	0.125
TruckM	125	0.750
TruckH	276	1.500

To project the capacity of battery packs in the future, we considered: (1) decrease in energy consumption/km; (2) desired range; and (3) the price of battery cells.

EV manufacturers have been able to consistently improve the overall energy efficiency of the vehicles, and this results in less energy consumption per kilometer and higher range on a single charge. To estimate the energy consumption (kWh/km) in the future, we referred to previous ICCT research[18] and unpublished work[19] of ICCT staff; we assumed a year-on-year decrease in energy consumption of 0.65% for two-wheelers, three-wheelers, cars, and utility and multi-purpose vehicles, and 0.70% year-on-year decrease for buses and trucks. We assumed that these yearly decreases would continue to be achieved through 2035.

Table 3 shows the average range offered by EVs in 2020 and the estimated desired range. We established the desired driving range based on the range on a single tank of fuel offered by conventional counterparts in India, the range offered by EVs available in the international market, and typical driving distances in India.

Table 3. Current and desired driving range of different EV categories in India

Vehicle category	Range in 2020, km	Estimated desired range, km
E-bike	73	100
2WLS	91	150
2WCS	93	200
2WHP	130	250
E-rickshaw	81	150
3W	90	150
PC	246	400
U&MPV	237	400
BusL	189	200
BusM	166	300
BusH	192	400
TruckL	175	250
TruckM	229	300
TruckH	261	400

The average cost of battery cells has dropped remarkably in the last decade and reached an average price of US$102/kWh in 2020.[20] This price reduction is a consequence of increased production volumes, rapidly advancing technology, more efficient supply chains, and decreased manufacturing costs. For this analysis, we assumed that cell-level costs will decrease by 7% per year till 2030 and thereafter by 5.5%, 4%, 3%, 2%, and 1% per year in the successive years till 2035; this would result in an average cell price of US$49/kWh in 2030 and US$42/kWh in 2035.

We assumed that EV manufacturers will keep the cost of battery packs constant and utilize the cost savings from cheaper cells to provide battery packs with proportionally larger capacity. We also assumed that manufacturers will *limit the increase once the net battery capacity provides the desired driving range*.

Figure 3 shows the forecasted net battery pack capacity by year.

18 Lutsey and Nicholas, "Update on electric vehicle costs."

19 Nihan Karali, Aditya Khandekar, Ben Sharpe, and Nikit Abhyankar, *Electrification of Indian trucking industry*, (Lawrence Berkeley National Laboratory: Washington, D.C.), unpublished manuscript.

20 "Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh", BNEF, December 16, 2020, https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/

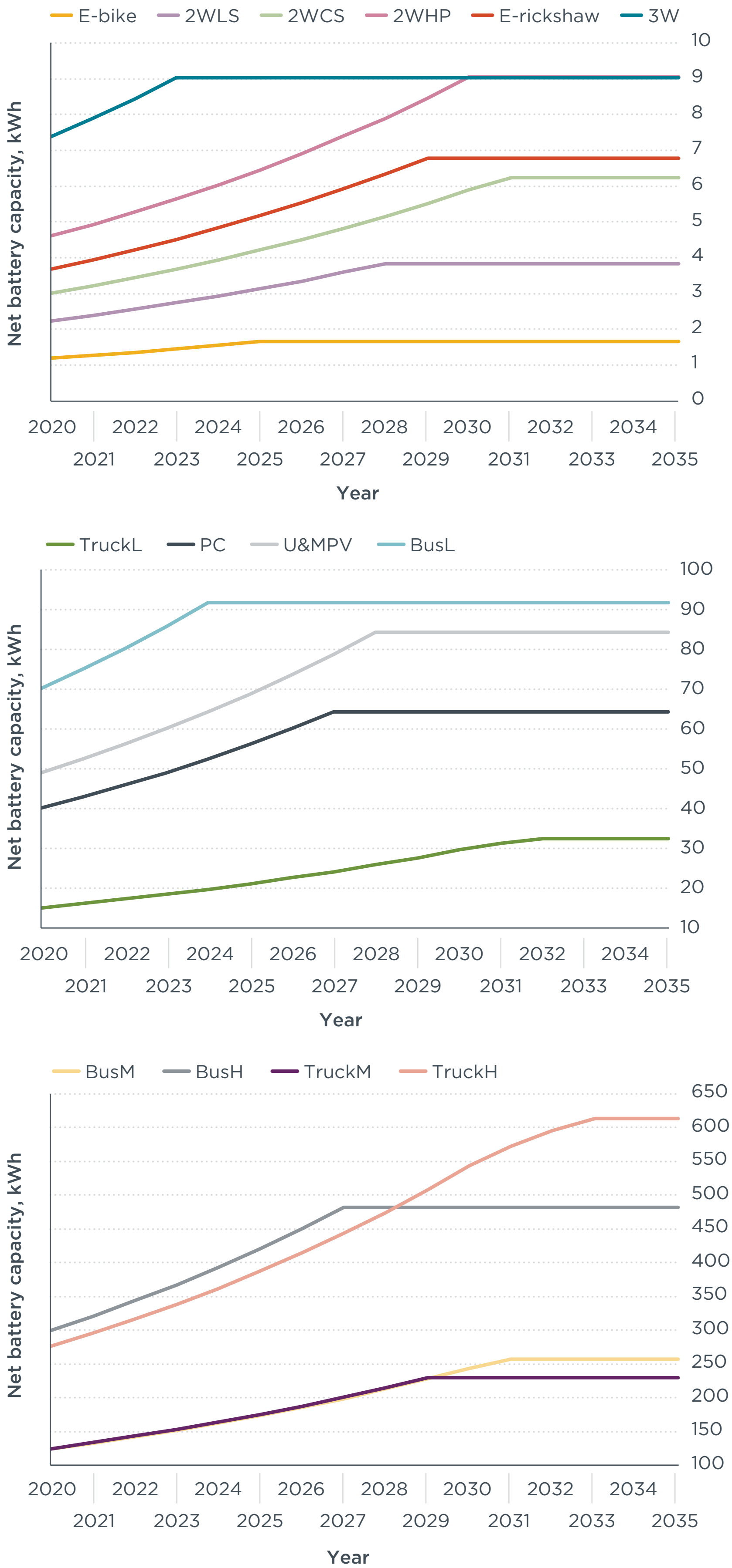

Figure 3. Forecasted net battery capacity of different EV categories, in kWh, 2020–2035

To estimate the gross battery capacity, we adopted the gross to net battery sizing ratio used by Volkswagen for the ID.3's battery design[21] and calculated the gross battery capacity based on the following formula:

$$\textit{Gross Battery Pack Capacity} = 1.07 \times \textit{Net Battery Pack Capacity}$$

Total battery capacity required

The increasing sales of EVs and the increasing capacity of the batteries utilized in EVs are both contributing factors to the growing demand for EV batteries. We calculated the aggregate battery capacity required in India by vehicle category using this formula:

$$\textit{Battery Capacity Required}_{year} = \textit{Gross Battery Pack Capacity}_{year} \times \textit{Sales}_{year}$$

Table 4 shows the estimated total battery capacity required by year in the 30@30 and Ambitious scenarios.[22] While it is outside the scope of this study, charging solutions such as battery swapping might cause a marginal increase in the demand for batteries in the short-term. However, this charging solution is not yet widely used in India.

Table 4. Total battery capacity requirement in the 30@30 and Ambitious scenarios, in GWh, 2020–2035

	30@30 scenario		Ambitious scenario	
Year	**Annual addition**	**Cumulative requirement**	**Annual addition**	**Cumulative requirement**
2020	2.2	2.2	2.6	2.6
2021	8.6	10.8	8.5	11.1
2022	12.7	23.5	13.2	24.3
2023	18.9	42.5	20.7	45.0
2024	28.2	70.7	32.8	77.8
2025	42.0	112.7	52.1	129.9
2026	62.2	174.9	81.9	211.8
2027	91.6	266.5	125.7	337.5
2028	130.3	396.8	183.6	521.2
2029	181.0	577.8	254.7	775.9
2030	246.9	824.7	338.2	1,114.1
2031	327.0	1,151.6	427.2	1,541.3
2032	416.6	1,568.2	513.9	2,055.2
2033	515.3	2,083.5	603.5	2,658.7
2034	618.1	2,701.6	693.7	3,352.4
2035	723.4	3,425.0	785.2	4,137.6

Apart from the 670 electric buses that are already deployed and the additional 2,450 electric buses that have been approved under FAME, there are virtually no other heavy-duty EVs currently in the Indian fleet. However, this is expected to change dramatically. Assuming that cost parity is achieved, we assume that there will be a rapid uptake of electric light buses and trucks in urban areas by 2028. We also assume rapid deployment of medium- and heavy-duty electric buses due to ambitious local and state-level policies, declining battery costs, and accelerated fleet replacement of diesel buses with electric buses instead of compressed natural gas buses. Our analysis, showcased in Figure 4, shows that buses and trucks will account for 18% to 25% of the cumulative battery demand from 2020 to 2035 due to the rapid increase in electrification of the heavy-duty segment.

21 "Volkswagen ID.3 Pro S," accessed October 9, 2020, https://ev-database.org/car/1203/Volkswagen-ID3-Pro-S
22 This estimate does not account for replacement batteries that some EVs may require during their lifetime.

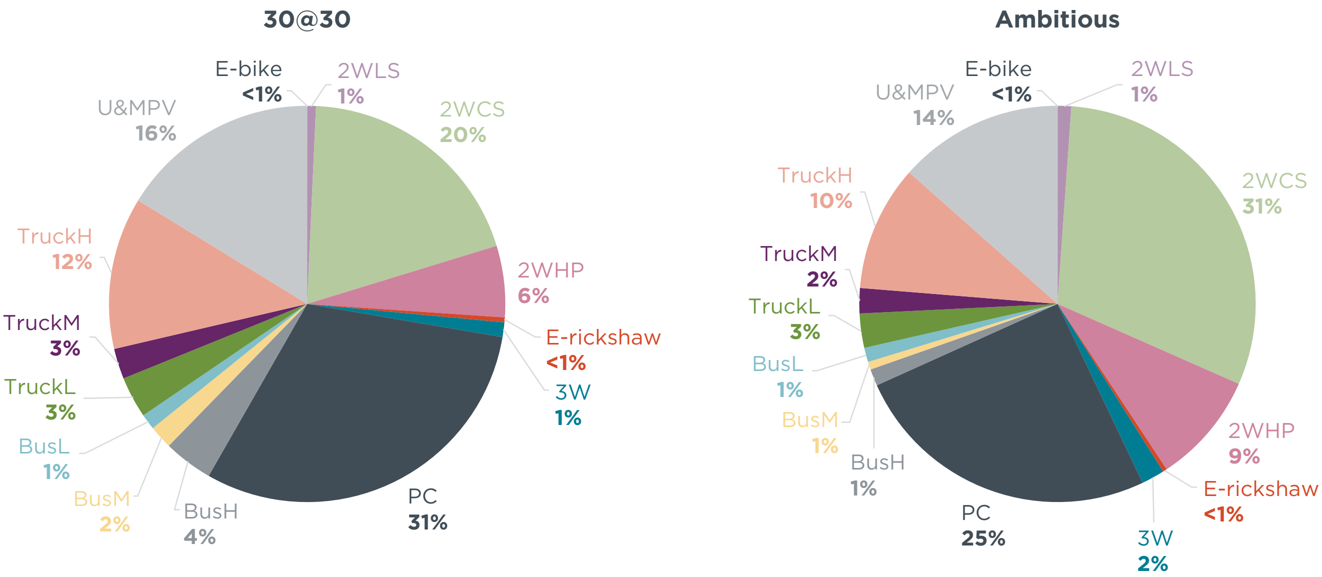

Figure 4. Contribution of different EV categories to cumulative battery capacity requirement by 2035

Discussion and conclusions

It is estimated that about 198 GWh of lithium-ion battery cells were produced worldwide in 2017. Based on commissions of major battery cell manufacturers, by 2022, it is estimated that annual global production capacity will increase to 600 GWh.[23] Our analysis indicates that India will need about 3,400 GWh to 4,100 GWh of batteries for its EVs by 2035. Moreover, in the next decade, India's annual requirement could be 17% to 26% of annual global production.[24] This highlights the need for India to set up its own *giga-factories* in the next few years. Giga scale production is a crucial part of lowering the price enough to make EVs cost competitive.

India's abundant labor force, relatively lower manufacturing costs, central geographic location for global trade, government ambitions, prowess in the manufacturing industry, and rapidly growing local vehicle market all present an opportunity for it to become a battery cell manufacturing and recycling hub for domestic and international markets. Localization of manufacturing would also present additional avenues for brand making, job creation, and growth of ancillary businesses. However, if India continues with only assembly of battery packs and does not manufacture battery cells, it will not reap the benefits of the associated economic activities.

Both leading global players and home-grown companies have announced plans to set up battery cell manufacturing facilities in India. TOSHIBA Corporation, Denso Corporation, and Suzuki Motor Corporation have jointly invested US$180 million to set up India's first lithium-ion battery *giga-factory* in Gujarat.[25] It will have an initial production capacity of 2.35 GWh. Japanese multinational electronic company TDK Corporation owns Amperex Technology Limited, which is planning to invest[26] US$945 million in India over the next few years to produce lithium-ion batteries for smart phones and EVs. The company has acquired 180 acres of land in the state of Haryana to set up a manufacturing plant. Tata

23 "Commissioned EV and energy storage lithium-ion battery cell production capacity by region, and associated annual investment, 2010–2022", IEA, April 10, 2020, https://www.iea.org/data-and-statistics/charts/commissioned-ev-and-energy-storage-lithium-ion-battery-cell-production-capacity-by-region-and-associated-annual-investment-2010-2022.

24 Global production is estimated to reach 1.3 to 1.45 TWh by 2030.

25 "What we are," TDS Lithium-Ion Battery Gujarat Private Limited (TDSG), https://www.tds-g.co.in/about-us.html

26 "Lithium-ion battery maker ATL buys 150 acres of land in Haryana; plans to invest Rs 7,000 crore in India," *Swarajya*, August 11, 2020. https://swarajyamag.com/insta/lithium-ion-battery-maker-atl-buys-180-acres-of-land-in-haryana-plans-to-invest-rs-7000-crore-in-india

Chemicals has committed to investing US$540 million to build a 10 GWh lithium-ion cell manufacturing plant in the state of Gujarat.[27] Based on these investment plans, we infer that an investment of around US$65 million per GWh of production capacity is required. Additionally, we estimate that about US$7 to $8 billion of investment is required in the cell manufacturing industry over the next 5 years, and at least US$50 to $70 billion of investment is required in the next 10 years, to build manufacturing capacity to keep up with domestic battery needs.

The US$2.4 billion of incentives that India has announced over the next 5 years are a strategic step in building a robust domestic battery industry. However, strengthening the entire ecosystem and value chain can be achieved by aligning the fiscal incentives for vehicle purchase with other regulatory targets. We discuss several of these below. In addition to the need to effectively structure incentives and other supporting policies, for any country, the challenges surrounding the sourcing of raw materials for producing battery cells at a large-scale are multi-faceted and constantly evolving.

Raw materials

Lithium-ion batteries use lithium nickel manganese cobalt oxide (NMC), lithium nickel cobalt aluminum oxide (NCA), lithium iron phosphate (LFP), or, to a limited extent, lithium manganese oxide (LMO) at the cathode; at the anode, graphite is used. Scaling up the production of these batteries in India would require a secure supply chain of raw materials. Among these, cobalt, lithium, nickel, and graphite are the most critical.

The geographic concentration of reserves and production of refined cobalt makes both its availability and price volatile. A typical NMC622 type cathode requires 0.22 kg/kWh of refined cobalt.[28] Higher capacity and low-cobalt NCA and NMC battery chemistries are being extensively researched and, if successful, will reduce the reliance on the mining of cobalt. For example, an NMC811 cathode chemistry requires just 0.09 kg/kWh[29] of refined cobalt. Additionally, while cobalt-free LMO- and LFP-based batteries offer relatively lower performance, their lower costs make them suitable for certain EVs.

The price volatility[30] of cobalt has catapulted the development of nickel-rich cathode chemistries. But while the demand created by the EV industry has renewed the interest in mining class 1 grade nickel, which was previously languishing because of the high price of class 1 grade nickel and limited demand, the mining industry has yet to find sustainable and economically viable methods to produce class 1 grade nickel in large quantities.

For lithium, the accessible reserves and production are concentrated in the salt lakes of Chile, Argentina, and Bolivia, and in Australia. Despite the availability of large reserves of lithium, the rapidly increasing demand might significantly increase the price in the short term. In the case of graphite, the supply chain of conventionally used natural graphite is largely dominated by China. Producing synthetic graphite might be an attractive alternative for India.

The cell chemistries that emerge dominant will depend on the energy density required, but more importantly on the availability and price of raw materials. However, the quantity of raw materials that are needed to produce battery cells at large scale should

27 "Tata planning Rs 4000 cr li-ion battery manufacturing plant in Gujarat", *Saur Energy International*, July 12, 2019, https://www.saurenergy.com/ev-storage/tata-planning-rs-4000-cr-li-ion-battery-manufacturing-plant-in-gujarat

28 Marcelo Azevedo et al., *Lithium and cobalt – a tale of two commodities*, (McKinsey & Company, June 2018), https://www.mckinsey.com/~/media/mckinsey/industries/metals%20and%20mining/our%20insights/lithium%20and%20cobalt%20a%20tale%20of%20two%20commodities/lithium-and-cobalt-a-tale-of-two-commodities.ashx

29 Ibid.

30 Peter Slowik, Nic Lutsey, and Chih-Wei Hsu, *How technology, recycling, and policy can mitigate supply risks to the long-term transition to zero-emission vehicles* (ICCT: Washington, D.C., 2020), https://theicct.org/publications/mitigating-zev-supply-risks-dec2020.

not be overlooked, especially as more demand means that less favorable natural resources will be mined at lower efficiencies. To ensure consistent supply of critical minerals to the Indian market, GoI set-up a joint venture of three central public service enterprises called Khanij Bidesh India Ltd. (KABIL).[31] Recently, KABIL led a strategic partnership with the state-run mining enterprise of Argentina for the exploration and production of lithium[32] and is exploring similar possibilities with Bolivia.[33]

By promoting and incentivizing cell chemistries with less cobalt and other sensitive materials, India can reduce its future reliance on mineral imports while developing critical technological capabilities. In this way, government policies can be structured to reduce the reliance of battery manufacturers on any particular set of raw materials.

Battery end of life

The calendric lifetime of a battery used in an EV is dictated by the electrode materials. It is further determined by the number of charge and discharge cycles, charging speed, and temperature of operation. Batteries are generally retired from automotive application when they can retain only about 80% of their initial stated capacity, and proper treatment of retired EV batteries will both reduce their life-cycle greenhouse gas emissions and maximize their economic value.

It is crucial to ensure that retired EV batteries are channeled toward suitable second-life use or, if not applicable, directly toward efficient recycling. They should be steered away from unorganized recycling processes or landfills, as these can cause serious environmental damage and pose serious health risks. The logistics of safely collecting, storing, and transporting batteries is difficult and expensive.

Recycling technologies that are currently popular around the world do not yield high recovery rates of lithium, cobalt, or nickel. Although other recycling technologies that overcome these limitations are available, they have not been scaled up due to the lack of availability of the necessary quantity of batteries at the end of life and the absence of regulation that mandates high recovery rates.

The European Commission requires that all retired EV batteries in European Union (EU) are collected for end-of-life processing. The Commission proposes[34] to increase the targets for the efficiency of recycling processes, as well as to establish a specific target for lithium-based batteries. As of January 1, 2027, EV batteries will have to declare the content of recycled cobalt, lead, lithium, and nickel contained therein. From January 1, 2030 onward, these batteries will have to contain minimum levels of recycled content (12% cobalt, 85% lead, 4% lithium, and 4% nickel). From January 1, 2035 onward, these levels will be further increased (20% cobalt, 10% lithium, and 12% nickel).

Before recycling, there are practical second-life applications of EV batteries. EV batteries that retain 80% of their original capacity might not be suitable for EVs, but are appropriate for less demanding applications such as grid-scale renewable energy storage. This strategy aligns with GoI's target of installing 175 GW of renewable energy capacity by 2022. It is estimated that these batteries can serve as energy banks

31 Government of India, Ministry of Mines, "KABIL set up to ensure supply of critical minerals," August 1, 2019, https://pib.gov.in/PressReleasePage.aspx?PRID=1581058

32 Samil Surendran, "India partners with Argentina for lithium supply," *Argus Media*, July 14, 2020, https://www.argusmedia.com/en/news/2122981-india-partners-with-argentina-for-lithium-supply

33 Government of India, Ministry of External Affairs, "Press briefing: India-Bolivia Relations," January 2020, https://mea.gov.in/Portal/ForeignRelation/Bolivia_Bilateral_brief_Jan_2020.pdf

34 "Questions and answers on sustainable batteries regulation," European Commission (December 10, 2020). https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_2311

until they deteriorate to 60% of their initial capacity[35] and this extends their economic life by another 10 years.

To address the proper treatment of retired batteries, GoI recently drafted an update to its Battery Waste Management Rules[36] 2001 with directives for battery waste management and recycling through the Extended Producer Responsibility (EPR) norms. EPR management requires that the battery manufacturer set up an effective waste battery channelization system via collection centers; implement a buy-back or exchange scheme; and make agreements with registered dismantlers or registered recyclers either individually or collectively or through a producer responsibility organization (PRO).

In addition to mandates on battery manufacturers for proper treatment of EV batteries at the end of life, there is a need for comprehensive policy measures that can ensure adequate supply of retired EV batteries for energy storage applications. Directives on scalable recycling technologies and regulations on recovery rates for strategic resources such as lithium, cobalt, manganese, nickel, and graphite are also essential.

Restructuring current incentives

The FAME scheme seeks to incentivize the purchase of 1 million electric two-wheelers, which would create demand for about 2.3 GWh of battery cells. However, an equivalent demand could be created by the sale of only 55,000 to 115,000 electric four-wheelers, since the capacity of the battery in an electric four-wheeler is roughly 10 to 20 times larger than the capacity of the battery in an electric two-wheeler. Although 14% of Indian automotive sales in recent years have been four-wheelers[37], only 6% of demand incentives in FAME are reserved for electric four-wheelers. By creating more impetus for the sale of electric cars in the immediate future, a greater demand for battery cells can be created in a shorter time frame.

To create more demand for the production of EV batteries in India, the next iteration of the FAME scheme should give greater weight to passenger cars and introduce purchase incentives for trucks.

Supporting policies

GoI instituted the FAME program to overcome the relatively higher up-front cost of purchasing EVs and the lack of public charging infrastructure. A few years after providing these demand-side incentives, the GoI has now proposed supply-side incentives for battery manufacturers. The ACC battery manufacturing scheme is a production-linked incentive, which means that subsidies are disbursed contingent upon the sale of the manufacturer's committed scale of production. Such a design ensures that a contracted quantity of batteries is available for EV manufacturers. However, if a matching demand does not exist from the EV sector, manufacturers will have to forgo the associated incentives, resulting in unprofitable giga-scale battery manufacturing.

To complement and bolster the ACC battery manufacturing scheme and ensure that there is sufficient demand from the EV sector, GoI should craft production mandates for zero-emission vehicle (ZEV) regulations[38] on all automobile manufacturers. The growth of EV models in China and the European Union suggests that ZEV mandates and stringent

35 David L Chandler, "Solar energy farms could offer second life for electric vehicle batteries", *MIT News*, May 22, 2020, https://news.mit.edu/2020/solar-energy-farms-electric-vehicle-batteries-life-0522

36 Government of India, "Notification: Draft – Battery Waste Management Rule of the Ministry of Environment, Forest and Climate Change," February 20, 2020, https://www.eqmagpro.com/wp-content/uploads/2020/02/Battery-Waste-Management-Rules-2020-draft.pdf.

37 Shikha Juyal et al., *Zero emission vehicles (ZEVs): Towards a Policy Framework*, (NITI Aayog and World Energy Council: 2018), http://niti.gov.in/writereaddata/files/document_publication/EV_report.pdf

38 Shikha Rokadiya and Zifei Yang, *Overview of global zero-emission vehicle mandate programs* (ICCT: Washington, D.C., 2019), https://theicct.org/publications/global-zero-emission-vehicle-mandate-program.

vehicle CO_2 standards can result in the introduction of more EV models and accelerate the rate of deployment of EVs.

GoI has set a bold agenda for the accelerated establishment of battery manufacturing facilities and this can stimulate economic growth and have far-reaching benefits for the economy. By investing in increasing its battery production capacity, India can reduce its reliance on fuel imports, enhance its technological abilities, and pave the way for its clean energy future.

Appendix. EV models available in India as of November 2020

Manufacturer	Model	Vehicle category	Declared battery capacity, kWh	Range, km	Energy consumption, kWh/km
Ampere	Reo	E-bike	1.2	55	0.022
Batt:Re	GPSie	E-bike	1.2	65	0.018
Batt:Re	IOT	E-bike	1.4	85	0.016
Batt:Re	Lo:EV	E-bike	1.2	65	0.018
Batt:Re	One	E-bike	1.4	85	0.016
Bgauss	A2	E-bike	1.3	110	0.012
Benling	Icon	E-bike	1.3	70	0.019
Benling	Kriti	E-bike	1.2	60	0.019
Benling	Falcon	E-bike	1.3	70	0.019
Detel	Easy	E-bike	0.6	60	0.010
Evolet	Derby Classic	E-bike	1.8	90	0.020
Evolet	Polo Classic	E-bike	1.2	100	0.012
Evolet	Pony Classic	E-bike	1.2	100	0.012
Hero Electric	Nyx E2	E-bike	1.3	55	0.024
Hero Electric	Optima e2 Li	E-bike	1.3	65	0.020
Hero Electric	Flash E2 Li	E-bike	1.3	65	0.020
Lohia Auto	Omastar Li	E-bike	1.0	60	0.017
Okinawa	R30	E-bike	1.3	60	0.022
Okinawa	Lite	E-bike	1.3	60	0.022
Pure EV	ETrance+	E-bike	1.3	65	0.020
Pure EV	Epluto	E-bike	1.8	80	0.023
Pure EV	ETrance	E-bike	1.0	70	0.014
Tunwal	Electrika 60	E-bike	1.9	100	0.019
Tunwal	Lithino-Li 2.0	E-bike	0.3	70	0.004
Tunwal	Storm ZX	E-bike	1.6	85	0.018
Tunwal	Mini Lithino	E-bike	0.3	70	0.004
Yo Bykes	Yo Edge DX	E-bike	0.3	60	0.006
Gemopai	Miso	E-bike	0.8	70	0.011
Li-ions Elektrik	Spock	2WLS	2.9	130	0.022
Benling	Aura	2WLS	2.9	120	0.024
Hero Electric	Nyx ER	2WLS	2.7	100	0.027
Hero Electric	Optima ER	2WLS	2.7	110	0.025
Hero Electric	Nyx E5	2WLS	1.3	50	0.026
Hero Electric	Photon LP	2WLS	1.9	75	0.025
Hero Electric	Optima e5	2WLS	1.3	55	0.024
Ampere	Magnus Pro	2WCS	1.8	75	0.024
Ampere	Zeal	2WCS	1.8	70	0.026
Ather	450 X	2WCS	2.9	85	0.034
Ather	450	2WCS	2.4	75	0.032
Avera	Retrosa	2WCS	2.6	140	0.019
Bajaj	Chetak Electric	2WCS	3.0	85	0.035
BGauss	B8	2WCS	1.5	70	0.021
Gemopai	Astrid Lite	2WCS	1.7	90	0.019
Go GreenBOV	Sunoti	2WCS	2.8	110	0.025
Jitendra New EV Tech	JMT1000HS	2WCS	2.0	90	0.022

Manufacturer	Model	Vehicle category	Declared battery capacity, kWh	Range, km	Energy consumption, kWh/km
NDS Eco motors	Lio	2WCS	1.5	100	0.015
Okinawa	i-Praise+	2WCS	3.3	139	0.024
Okinawa	Praise Pro	2WCS	2.0	80	0.025
Okinawa	Ridge+	2WCS	1.8	60	0.030
Pure EV	Epluto 7G	2WCS	2.5	90	0.028
Pure EV	Etrance Neo	2WCS	2.5	120	0.021
Revolt	RV 400	2WCS	3.2	100	0.032
Revolt	RV 300	2WCS	2.7	110	0.025
TVS	iQube	2WCS	2.3	75	0.031
Joy E-Bike	E-Monster	2WCS	2.9	100	0.029
Emflux	One	2WHP	9.7	200	0.049
Evolet	Hawk	2WHP	2.9	100	0.029
Evolet	Raptor	2WHP	2.9	150	0.019
Everve Motors	EF1	2WHP	4.4	100	0.044
Tork	T6X	2WHP	3.5	100	0.035
Ultraviolette	F77	2WHP	4.2	130	0.032
Autolite	Supreme	E-rickshaw	3.8	90	0.043
Mahindra	Treo Yaari	E-rickshaw	3.7	85	0.043
Omega Seiki	Ride	E-rickshaw	Not Available	Not Available	Not Available
Gem EV	Samrat	E-rickshaw	3.4	70	0.048
Gatti	Gatti	E-rickshaw	3.8	80	0.048
Mahindra	Treo	3W	7.4	130	0.057
Omega Seiki	Singha Max L5	3W	10.5	100	0.105
Omega Seiki	Singha	3W	7.6	100	0.076
Omega Seiki	Rage	3W	7.5	75	0.100
Omega Seiki	Rage+	3W	6.0	75	0.080
Omega Seiki	Sun Ri	3W	Not Available	Not Available	Not Available
Omega Seiki	Stream	3W	Not Available	Not Available	Not Available
Evolet	e3	3W	7.37	120	0.061
VidyutEV	C1	3W	6.6	65	0.102
Kinetic	Safar Shakti Star	3W	3.6	55	0.065
Kinetic	Safar Shakti Star MSV L5	3W	4.5	65	0.069
Gayam	Taskman Cargo	3W	4.8	110	0.044
Keto Motors	BulkE	3W	8.1	100	0.081
Gem EV	Super King	3W	3.8	60	0.064
Altigreen		3W	10.0	120	0.083
Tata	Nexon EV2	PC	30.2	200	0.151
Tata	Tigor	PC	21.5	213	0.101
Mahindra	e2oPlus P2	PC	15.0	140	0.107
Mahindra	e-Verito	PC	21.2	150	0.141
Hyundai	Kona	PC	39.2	250	0.157
MG Motors	ZS	PC	42.5	320	0.139
Mercedes Benz	EQC	PC	76.4	450	0.170
BYD	T3 MPV	U&MPV	50.3	300	0.168
Citroen	e-Dispatch**	U&MPV	50	229	0.219
Citroen	e-Dispatch**	U&MPV	75	328	0.229

Manufacturer	Model	Vehicle category	Declared battery capacity, kWh	Range, km	Energy consumption, kWh/km
Citroen	e-Relay**	U&MPV	44	224	0.196
Fiat	E-Ducoto**	U&MPV	47	220	0.214
Fiat	E-Ducoto**	U&MPV	79	360	0.219
Maxus	eDeliver3 LWB**	U&MPV	35	155	0.226
Maxus	eDeliver3 LWB**	U&MPV	52.5	235	0.223
Maxus	eDeliver3 SWB**	U&MPV	35	220	0.159
Maxus	eDeliver3 SWB**	U&MPV	52.5	330	0.159
Renault	Kangoo ZE**	U&MPV	33	229	0.144
Mercedes	eVito**	U&MPV	41	150	0.273
VW	e-Transporter**	U&MPV	28	131	0.213
Ford	eTransit**	U&MPV	67	202	0.332
Nissan	E-NV200**	U&MPV	40	240	0.167
Saturn	City Van**	TruckL	13	104	0.125
Saturn	City Van**	TruckL	26	200	0.130
Mahindra	eSupro	TruckL	14.4	115	0.125
Alke	ATX 340E**	TruckL	20	200	0.100
Tropos Motors	ABLE XR**	TruckL	26	256	0.102
Tata	Ultra T.7 Electric	TruckM	62.5	100	0.625
BYD	T5**	TruckM	150	248	0.605
BYD	T7**	TruckM	170	198	0.857
Daimler	eM2 106**	TruckM	315	368	0.856
Lion Electric	Lion 6**	TruckM	252	288	0.875
IPLT	5536 (Rhino)	TruckH	276	184	1.500
Daimler	eActross**	TruckH	240	200	1.200
Daimler	eCascadia**	TruckH	475	400	1.188
Lion Electric	Lion 8**	TruckH	336	272	1.235
Karsan	Jest**	BusL	44	105	0.419
GreenPower	EV Star**	BusL	118	240	0.492
Mellor	Orion**	BusL	72	160	0.450
Hyundai	County**	BusL	128	250	0.512
Hyundai	Elec City	BusM	128	145	0.883
Tata	Starbus 9m	BusM	124	150	0.827
Olectra	K7	BusM	160	200	0.800
PMI Electro Mobility	Lito	BusM	102	168	0.607
Olectra	K9	BusH	324	250	1.296
Tata	Starbus 12m	BusH	186	200	0.930
Evolet	Lancer	BusH	221	200	1.105
PMI Electro Mobility	Regio	BusH	102	168	0.607
PMI Electro Mobility	Urban	BusH	152	144	1.056
JBM Group	EcoLife 9m	BusH	150	200	0.750
JBM Group	EcoLife 12m	BusH	200	160	1.250
Ashok Leyland	Circuit	BusH	230	140	1.643

**Not available in the Indian market, for reference only