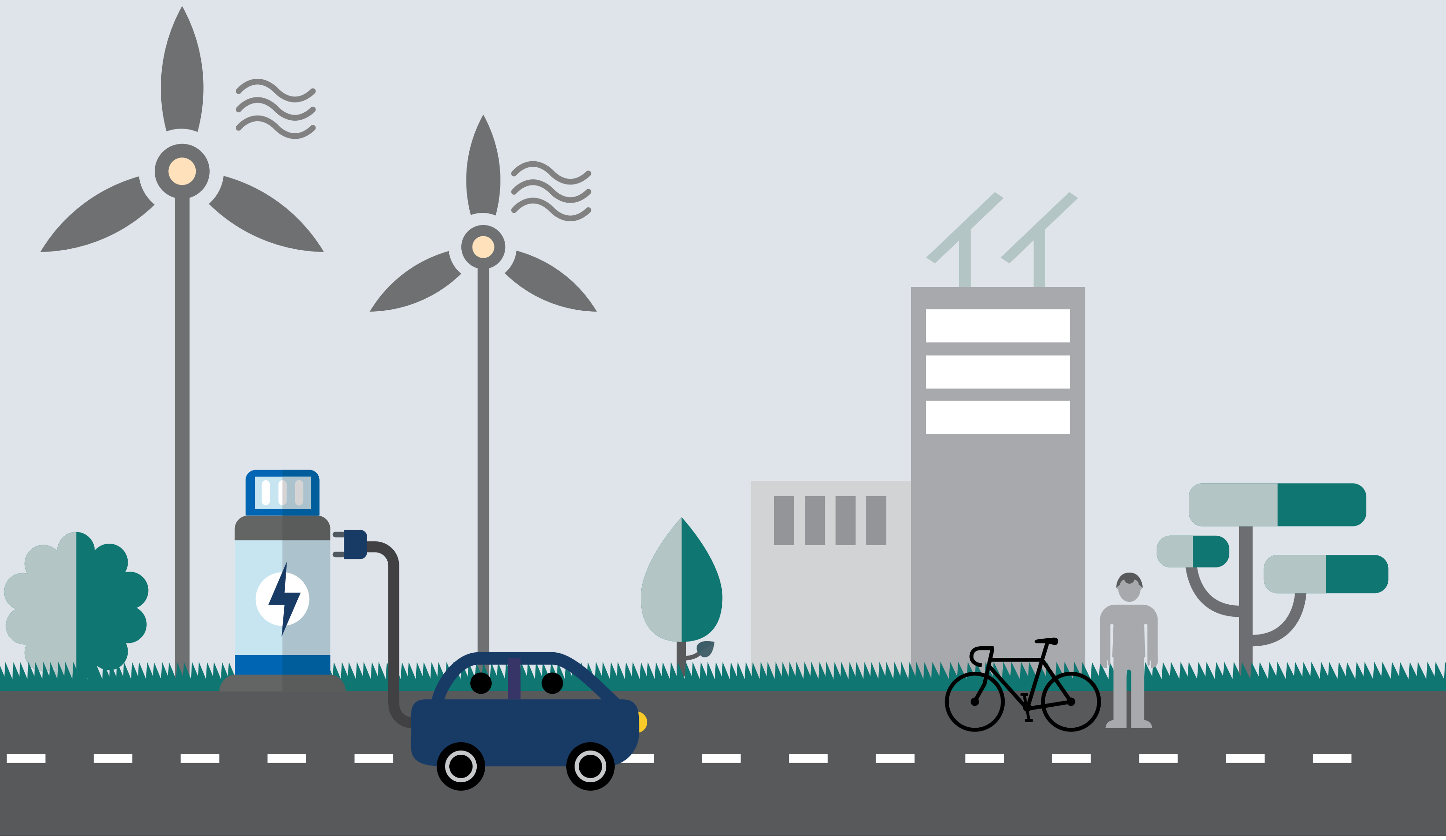
ENABLING THE TRANSITION TO ELECTRIC MOBILITY IN INDIA



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About FICCI

Established in 1927, FICCI is the largest and oldest apex business organisation in India. Its history is closely interwoven with India's struggle for independence, its industrialization, and its emergence as one of the most rapidly growing global economies.

A non-government, not-for-profit organisation, FICCI is the voice of India's business and industry. From influencing policy to encouraging debate and engaging with policymakers and civil society, FICCI articulates the views and concerns of industry.
It serves its members from the Indian private and public corporate sectors and multinational companies, drawing its strength from diverse regional chambers of commerce and industry across states, and reaching out to over 2,50,000 companies. FICCI provides a platform for networking and consensus building within and across sectors and is the first port of call for Indian industry, policymakers and the international business community.

About Rocky Mountain Institute

Rocky Mountain Institute (RMI) is an independent, apolitical, nonprofit think-and-do tank that transforms global energy use to create a clean, prosperous, and secure future. For more than three decades, RMI's work in the transportation sector has described and helped to concretely advance solutions that are both visionary and pragmatic, ranging from advanced vehicle designs to new mobility-services concepts. RMI's staff of scientists, engineers, and business leaders has helped governments, utilities, large corporations, innovative startups, and communities understand and benefit from the new energy economy with the imaginative application of rigorous technical and economic analysis. In recent years, RMI has developed electric vehicle (EV) deployment plans to reach 100% EV penetration for the U.S. and China. Cofounded by Amory Lovins in 1982, RMI has been a leader in energy efficiency and renewable energy for 35 years.

ENABLING THE TRANSITION TO ELECTRIC MOBILITY IN INDIA

FICCI Smart Mobility Conference
New Delhi, India
20 November 2017

Prepared by **Rocky Mountain Institute**

Design: Infonauts, www.infonauts.in

Foreword

Mr K Ramchand

Chairman, FICCI National Committee on Infrastructure and Managing Director, IL&FS Transportation Networks Ltd

I am happy to share with you the FICCI-Rocky Mountain Institute (RMI) report on **'Enabling the Transition to Electric Mobility in India'** to be released at the Smart Mobility Conference organized by Federation of Indian Chambers of Commerce and Industry.

Efficiently managing the mobility of people in a sustainable manner would be a key challenge for Indian cities. Hence, a viable solution to these entwined and complex challenges lies in implementing smart mobility solutions. Optimizing e-mobility use for everyday life with greater thrust on use of public transport, e-vehicles, metro solutions and shared rides as means for mass transit could prove game-changers in addressing the issue of air pollution in urban areas.

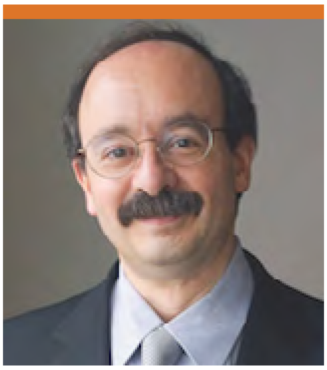
Government has taken several reforms towards creating an ecosystem for electric mobility in the country. The ambitious aim of becoming 100 percent electric vehicle nation by 2030, the FAME (Faster adoption and manufacturing of Hybrid and electric vehicles) program and the new Metro Policy 2017 are steps towards achieving this goal. Indian government has further pushed the Indian automotive companies to expedite the electric vehicle manufacturing in the country and is working towards a policy surrounding electric mobility and storage.

The Smart Mobility Conference aims to lay down a roadmap for the future, driven by innovation and the vision to provide cleaner, safer and faster transportation infrastructure. The Conference will focus on electric vehicles, creating economically-viable and shared infrastructure, development of urban metro rail system, adopting intelligent transportation system and digital technologies to improve effectiveness, efficiency and safety.

As a 'knowledge Partner' for the event, RMI has prepared a comprehensive background paper covering a large number of important aspects. The FICCI-RMI report on **'Enabling the Transition to Electric Mobility in India'** highlights the way forward to accelerate electric mobility in India while addressing the key areas of shared mobility services, interoperable transport data, EV charging infrastructure and manufacturing.
The report has been prepared through detailed analysis of several critical factors and global case studies influencing smart mobility.

I hope you will find this report useful and as always, your suggestions and feedback are welcome.

Foreword



Amory Lovins,

Co-Founder and Chief Scientist,
Rocky Mountain Institute

The pace of energy transformation has always been remarkable. On New York City's Fifth Avenue, in 1900 there were few cars among a fleet of horses. Yet 13 years later there were few, if any horses remaining. In the U.S., car-owning households soared from 8% to 80% in a decade, as the Ford Model T became 62% cheaper in 13 years, and GM and DuPont developed an innovative financing mechanism called car loans. Recently, global solar PV and battery prices have dropped 80% in five years. Signs indicate that the pace of India's energy transformation could be astonishing: the nation singlehandedly reduced the cost of LEDs by 80% in one year, and the Government of India has set its sights on an ambitious target of 100% electric vehicles by 2030.

Transformation happens when savvy technologists rapidly reduce hardware costs and innovative entrepreneurs simultaneously develop new business models to economically deploy this hardware. India is a country full of these changemakers, and already members of the government, private sector, and civil society are quickly shaping India's mobility transformation. As India begins to design cities around feet, not cars; put more people in fewer vehicles; and produce more efficient, peppy, and appealing vehicles that provide both mobility services and valuable services to the electric grid, I am confident that this ambitious country, drawing on the ideas in this report, will enable the transformation of electric mobility in India and around the world.

Contents

Executive Summary

This report discusses the potential of electric mobility in India, the key challenges to electric vehicle (EV) adoption, lessons from global case studies, and the way forward, across six topics: public transport; sharing and mobility services; interoperable transit data; EV charging infrastructure; battery swapping; and battery manufacturing.

One by one, the main barriers to EV adoption — price, selection, range, charging, and consumer awareness — are falling due to steeply falling technology costs, business-model innovation, and increasing connectivity. India can accelerate its EV adoption by addressing these key challenges through a whole-systems approach. This report discusses potential solutions to these challenges across six areas of the passenger mobility sector:

- **Public Transport,** to reduce congestion on roads, the cost of transportation for travelers, transportation energy use, and negative environmental impacts
- **Sharing and mobility services,** to unlock the competitive and often superior economics of high-mileage EVs through a variety of innovative business models, while creating jobs and enhancing access to India's critical public transit network;
- **Interoperable transit data,** to enable sharing and mobility services, as well as better access, affordability, and multimodal integration;
- **EV charging infrastructure,** to power EVs and to provide valuable grid services, reducing customers' concerns around range anxiety and enhancing India's rapidly changing electric grid;
- **Battery swapping,** to reduce the upfront cost of EVs and to complement EV charging infrastructure through a more centralized, less distributed form of charging EV batteries; and
- **Battery manufacturing,** to reduce the cost of batteries—currently the most expensive EV component—and to make them in India, thereby accelerating EV adoption, both in India and globally, while creating jobs and avoiding a future in which India replaces costly oil imports with lithium imports.

Overcoming key barriers to vehicle electrification in India's passenger mobility sector presents an enormous challenge for India—and also a tremendous economic opportunity. India can leapfrog the western mobility paradigm of private-vehicle ownership and create a shared, electric, and connected mobility system, saving 876 million metric tons of oil equivalent, worth US$330 billion (INR 20 lakh crore), and 1 giga-tonne of carbon-dioxide emissions by 2030. Using a collaborative approach, coordinated action, and the strategies and solutions in this report, India can overcome key barriers to EV adoption and potentially become a global leader in electric mobility.

Introduction

India's passenger mobility sector is on a path to rapid transformation. In March 2016, the Government of India set the country's sights on an ambitious target of 100% electric vehicles (EVs) by 2030. Since then, India has seen early signs of the rubber meeting the road in its public and private sectors.

Vehicle aggregators are exploring opportunities to deploy electric cabs in major cities.[1] The Government of India is considering an electric fleet.[2] The Department of Heavy Industry recently revised its incentive scheme, known as the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India, to more aggressively encourage EV adoption, including electric buses for public transportation.[3] Central and state governments are investing in integrated transport hubs for multimodal logistics and transportation.[4] And several original equipment manufacturers (OEMs) are partnering on domestic manufacturing of lithium-ion batteries.[5] The Government of India's stated goal and early signs of private-sector action indicate that a broad set of actors understand the value of India's mobility transformation and are already taking steps to capitalize on new opportunities created by this emerging market.

Estimates indicate that India's urban population will nearly double in the next decade, from 377 million in 2011 to approximately 600 million in 2030,[6] and forecasts suggest that by then India's urban population will take almost 500 million trips per day.[7] While this rapid growth presents major policy and business challenges for India's public and private sectors, respectively, it also presents an enormous economic opportunity. India's transition to a shared, electric, and connected mobility system can save US$330 billion (INR 20 lakh crore) by 2030 on avoided oil imports alone.

If India is successful in reaching its EV target, the market could be enormous. Even under a shared mobility paradigm, over 46,000,000 vehicles (two-, three-, and four-wheelers) could be sold in 2030 (please see Table 1). This annual market size would present an opportunity for Indian companies to become leaders in EV technology on a global scale.

Segment	Technology	Year		
		2020	2025	2030
Motorcycles and scooter	Non-EV	10,409,000	9,260,000	0
	EV	7,352,000	14,035,000	26,514,000
Autorickshaws	Non-EV	616,000	0	0
	EV	646,000	2,364,000	4,072,000
Cars and Jeeps	Non-EV	3,538,000	3,932,000	0
	EV	26,000	1,592,000	15,911,000
Total	Non-EV	14,563,000	13,192,000	0
	EV	8,024,000	17,991,000	46,497,000

Table 1. Annual market sizes of the two-, three-, and four-wheel vehicle segments for conventional and EV technologies in 2020, 2025, and 2030. Source: NITI Aayog and RMI Analysis

By 2027, 4-wheel EV sales may exceed 4-wheel ICE sales (please see Figure 1). After this intersection point, 4-wheel EV sales will grow rapidly, with nearly 16 million 4-wheel EV sales in 2030. While achieving 100% EV sales by 2030 is challenging, doing so would create a major business opportunity for automakers. Realizing this goal would have a significant impact on India's vehicle stock, with a nearly equal split between ICEs and EVs by 2030 in the 4-wheel segment (please see Figure 2). This projection conservatively does not take into account India's potential impact on global battery pack prices, which would likely push forward all of these dates.

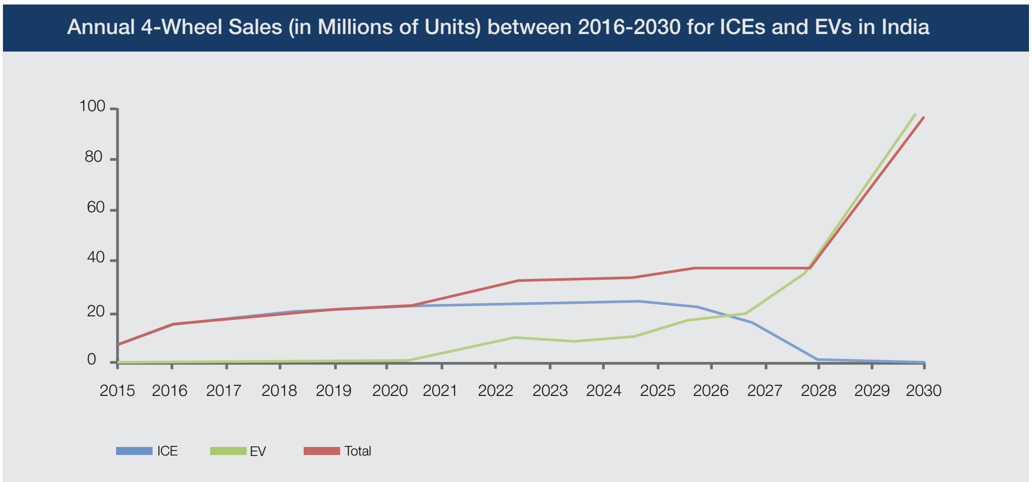


Figure 1. Annual sales of 4-wheel EVs will exceed those of 4-wheel ICEs around 2028, with EVs accounting for 100% of 4-wheel sales by 2030. Source: RMI analysis

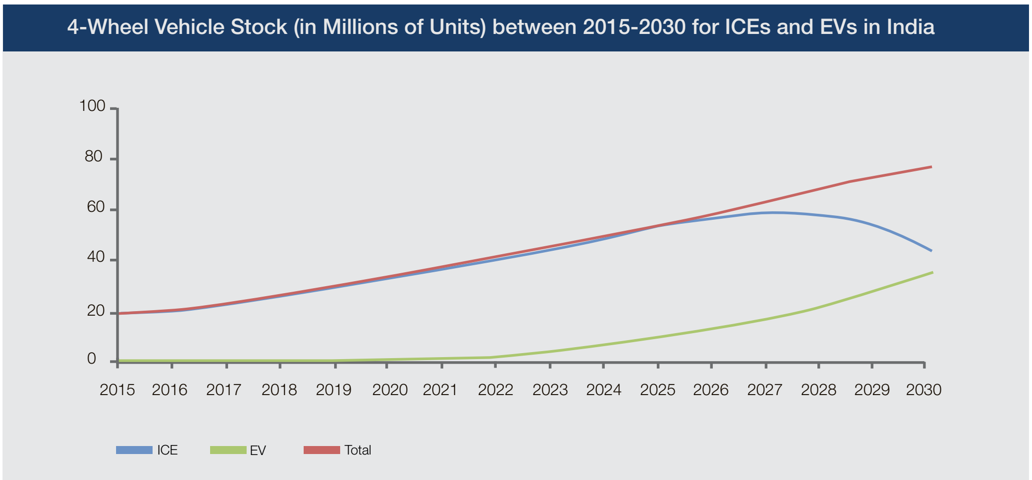


Figure 2. 4-wheel vehicle stock will be a nearly equal share of ICEs and EVs by 2030. Source: RMI analysis

Enabling India's electric mobility opportunity will require addressing key challenges through a whole-systems approach. This report discusses the potential of electric mobility in India, the key challenges to EV adoption, lessons from global case studies, and the way forward, across six topics: public transport; sharing and mobility services; interoperable transit data; EV charging infrastructure; battery swapping; and battery manufacturing.

The strategies and solutions discussed in this report suggest that India's public and private sectors—through a collaborative approach and coordinated action—are capable of capitalizing on this extraordinary economic opportunity. This report aspires to encourage all Indian stakeholders to consider not only how their solution can contribute to this vision, but also how they can work together across different parts of the mobility system to collectively create more value for all Indians.

1 Public Transport: Efficiently and Affordably Mobilizing Cities

Key recommendations for shaping the way forward:

Design urban environments to encourage greater access to and the use of public transport. Develop physically and digitally connected transport hubs to enable multimodal mobility that prioritizes public and non-motorized transport. Deploy affordable, reliable, and comfortable public transport by introducing incentives that value the societal benefits of public transport, such as lower congestion and emissions. Economic electrification of public transport services could bring additional benefits.

1.1 The Current State of India's Public Transport System

India's public transport systems are in a state of transition. Currently, India has one of the highest rates of public transport use in the world, averaging almost 25% (excluding non-motorized transit) across major cities; 90% of this share is from buses, which can account for 30–40% of the mode share in major Indian Cities (please see Figure 3)[8]. However, a significant portion of this use stems from necessity: public and non-motorized modes of transport are the only options many Indians can afford.

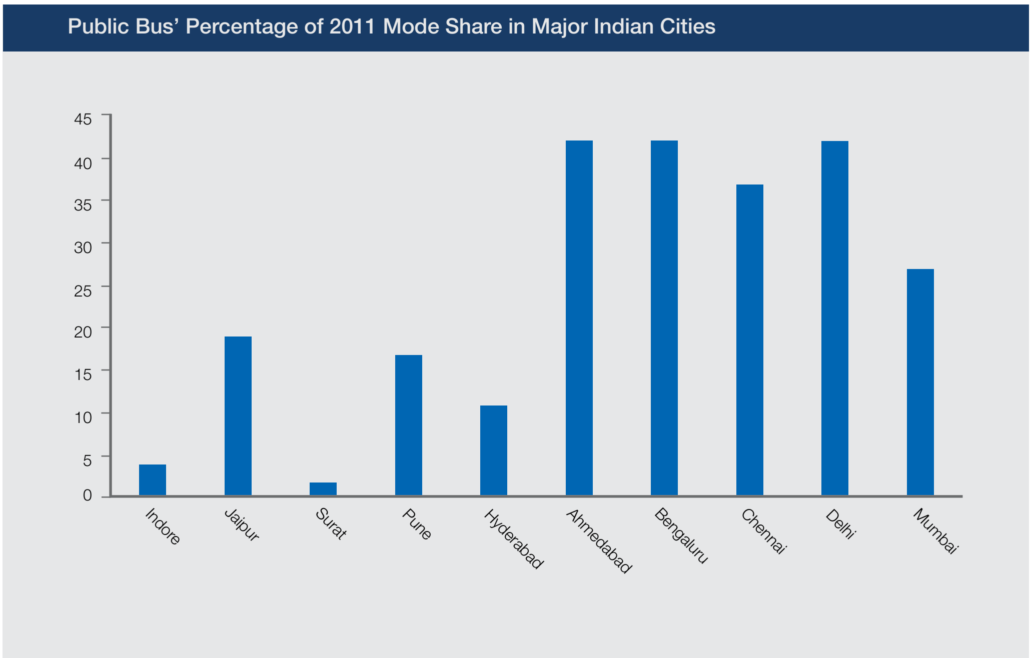


Figure 3. Public bus' percent of the mode share can be as high as 30–40% in major Indian cities.

In cities like Delhi, the use of bus services is declining [9], with passenger ridership falling 11% between 2014 and 2015; the number of buses is also declining. Much of this demand loss is due to Indians' increasing wealth: more urban dwellers can now afford to buy a two- or four-wheeler or to take a ride-hailing service instead of the bus. As Indians' wealth continues to grow, this trend will become a more pervasive issue. Increasing the utilization of India's public transport will require careful planning around non-motorized transport, as well as first- and last-mile solutions that connect citizens from their homes and workplaces to public transport options. A major opportunity exists for India to design cities and make investments in order to dramatically increase the utilization of public transport.

1.2 OPPORTUNITIES TO MAINTAIN AND IDEALLY INCREASE THE UTILIZATION OF PUBLIC TRANSPORT IN INDIA

To maintain and ideally increase the utilization of public transport in India, the following actions represent key opportunity areas for system improvement:

1. Following principles of mobility-oriented development, build or modify urban environments around moving people, not cars by:
   - Developing high-density, mixed-use environments where employment, shopping, and recreational activities are in close proximity, thereby reducing citizens' daily travel;
   - Locating high-density environments along transport corridors served by mass-transit and effectively matching density and transit capacity;
   - Ensuring efficient mobility options, such as public transit, are within walking distance of urban centers;
   - Providing transport hubs that link different modes of transport, thereby creating a seamless, multimodal system; and
   - Maintaining walking and biking as viable, attractive modes of transport by developing specific, non-motorized transport infrastructure, such as protected paths and crosswalks.

2. Develop cities with efficient mobility systems, municipalities should consider creating Metropolitan Planning Councils (MPCs). These entities are responsible for integrated land-use and transportation planning, creating comprehensive strategic mobility plans that help develop policies with alignment across stakeholder groups and their objectives. With the power to plan, implement, and monitor, MPCs can launch successful programs and pilots with solutions that target specific regions' unique conditions.

3. Launch pilots and programs to test new mobility solutions, including first- and last-mile transit options by developing partnerships between public transport systems and mobility service providers, as well as IT-enabled platforms, to help travellers reach transport hubs more efficiently and affordably.

4. Encourage micro-transit options—affordable, on-demand intermediary transport solutions—in India's cities to provide critical first- and last-mile solutions. These micro-transit options can boost the utilization of public transport and offer a middle-tier between shared cars and buses or metros. Encouraging such micro-transit options can have a significant impact on reducing congestion and private vehicle ownership, while promoting a higher use of public transit.

1.3 EXPANDING INDIA'S DEFINITION OF PUBLIC TRANSPORT THROUGH DATA AND NEW BUSINESS MODELS

Common payment platforms and trip planning can connect public transport and micro-transit options. New integrated data, technology, and service platforms, like Go LA and TransLoc, make it easy for users to plan trips across multiple modes, with mass-transit options generally providing the backbone service for riders. Building on India's rapidly growing digital economy, these common booking and payment platforms can further enhance convenience and comfort for Indian travellers.

In many cases, technology platforms, such as Jugnoo, make it easier for users to find and access first- and last-mile solutions, boosting the utilization of public transport. It is generally difficult for public transport operators to effectively and affordably provide these services. Coverage in low-density or remote neighborhoods is possible with such platforms. India can promote and proliferate these offerings by integrating payments across public and intermediary modes of transport, as well as sharing real-time data that helps riders plan their trips more easily.

Alternative transit options, like Chariot or Via in the U.S., offer flexible and often higher-quality transit options to riders in "affinity groups." These affinity groups could be co-located workers or riders from the same university or residential enclave. Availability of such services has a direct and significant impact on reducing personal-vehicle ownership and, importantly, higher use of public transport

1.4 INDIA'S PATH FORWARD IN PUBLIC TRANSPORT

Maintaining a high mode share for public transport in India is not only a path to lower congestion and energy use, but also a path to lower system costs. Shifting to infrastructure built for privately owned vehicles requires many more lane-kilometers of roads to meet travelers' needs. Since private vehicles underutilized assets, Indians could contribute to the economy more by investing their money elsewhere.

As India looks ahead, reducing the number of vehicles on the road leads to the most reduction in congestion and energy use. The economic savings that Indian cities can potentially achieve through less spending on infrastructure are a major bonus (please see Figure 4). India should work toward a future that keeps the utilization of public and non-motorized transport high. If citizens walk or bike for many of their needs, use mobility services for intermediate trips, and public transport for farther travel, India would spend much less on infrastructure and related operating expenses—freeing up funds to develop India's economy in other ways (see section 6 on battery manufacturing).

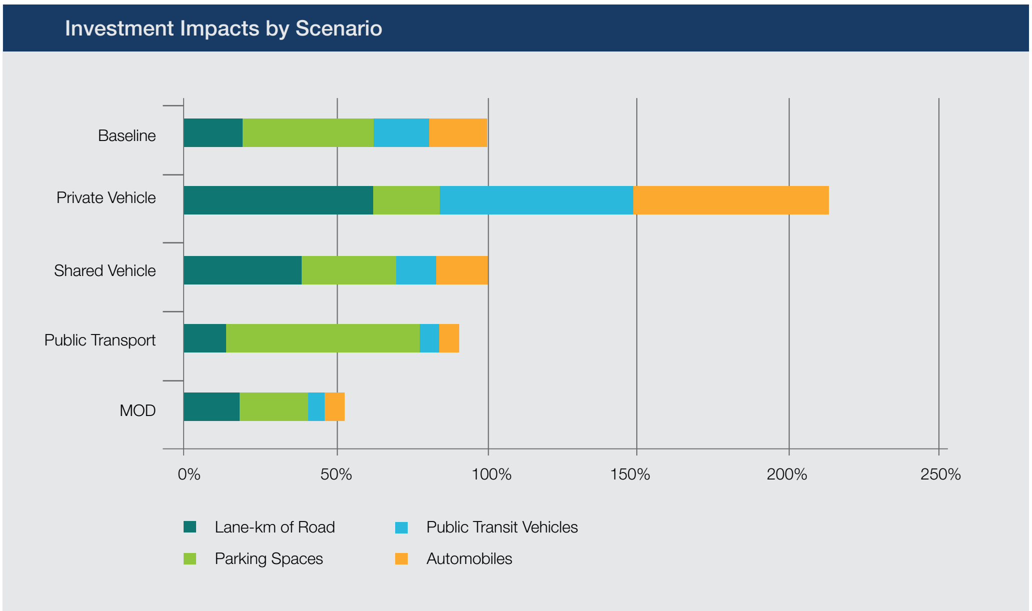


Figure 4. City-level infrastructure investment that focuses on private-vehicle ownership is over twice the cost of baseline infrastructure spending and nearly four times the cost of cities designed using the principles of mobility-oriented development.

2 Sharing and Mobility Services: Unlocking Economic Electrification

Key recommendations for shaping the way forward:

Target shared and fleet vehicles— including two-wheelers, three-wheelers, and government fleets—for immediate electrification given their favorable economics. Introduce policies and incentives that further encourage sharing and electrification, especially in intermediate and public transport applications.

2.1 THE BUSINESS CASE FOR SHARED, ELECTRIC MOBILITY SERVICES

Mobility systems around the world are undergoing rapid transformation due to new business models, steeply falling technology costs, and increasing connectivity. Global projections for EVs show rapid deployment over the coming decades. While EV sales are already growing in many nations, designing mobility systems to encourage sharing and mobility services can accelerate EV adoption because shared, electric mobility services offer competitive and often superior economics, as well as new value streams and job creation opportunities.

Industry analysts predict that the initial purchase price of an electric passenger car will equal that of a comparable internal combustion engine (ICE) vehicle by 2025 [10]—a tipping point that will dramatically accelerate EV adoption. This reduction in upfront capital cost is largely a result of a more than 65% decrease in batteries' per-kilowatt-hour cost between 2011 and 2016 [11].

Globally, EVs already benefit from lower operating and maintenance (O&M) costs. These lower O&M costs are mainly due to electricity's lower per-kilometer (km) cost than gasoline[12] and EVs' many fewer parts—20 for an EV vs. about 2,000 for an ICE[13] —and thus fewer maintenance requirements and breakdowns. In India, for example, a privately owned, four-wheel ICE's operating cost (US$0.27/km) is three times higher than a shared, four-wheel EV (US$0.09/km)[14]. In several geographies, four-wheel EVs have already reached price parity on a total cost of ownership (TCO) basis in high-utilization (>32,000 km/year) applications.

In India, manufacturers, operators, and consumers should prioritize electrifying and scaling successive sets of market segments as they become economic. The two- and three-wheel segments are currently economic in India. Electric two-wheelers' capital and operating costs are INR 34,000–50,000 and INR 0.06–0.4/km, respectively. While ICE two-wheelers' capital cost can be lower (INR 25,000) in some cases, they can be higher (INR 70,000) in other cases. However, ICE two-wheelers' operating cost is significantly higher (INR 1–1.5/km), advantaging EV models on a TCO basis[15]. Electric two-wheelers also benefit from considerably lower emissions, with electric bikes saving 350 kg of CO2 per year[16]. Electric three-wheelers are already superior to ICE models in terms of capital (INR 80,000–150,000 vs. INR 144,000–300,000) and operating (INR 0.45–1/km vs. INR 1.84–3.5/km) costs.

Electric four-wheelers and buses will become economic over time. Today, a four-wheel Indian EV costs INR 7 lakh, whereas a four-wheel Indian ICE generally costs less, between INR 4.8–7.4 lakh. Putting each of these vehicles into mobility-service applications, however, could soon tilt the economics in favor of the EV model, which benefits from over 40% lower operating cost (INR 2/km vs. INR 3.5/km). Buses may take longer to become economic, as some electric buses are still over 10 times more expensive than comparable ICE models. Rapidly falling battery pack prices and solutions like battery swapping may help shorten this timeline[17].

In many respects, car ownership is an economically irrational choice. In the U.S., for example, vehicles are parked, sitting unutilized, 95% of the time [18], despite being the average household's second highest annual expense (US$15,000 per household)[19]. U.S. vehicles are also underloaded: over 75% of commuters drive alone [20]. Putting vehicles into service, through innovative business models like transportation network companies (TNCs) or vehicle sharing companies (e.g., ZipCar), can increase asset utilization and thus make electrification economic.

Ride hailing, pooling, vehicle sharing, and commuting offer promising entry points to economic vehicle electrification in India. On-demand mobility services are already growing in market share. These innovative business models put more people in fewer vehicles that drive more frequently, allowing drivers (or fleet owners) to benefit from EVs' lower O&M costs, riders to benefit from lower fares, and citizens and cities to benefit from a more efficient system. These economic and social factors support the proliferation and electrification of shared mobility services.

2.2 EXAMPLES OF SHARED MOBILITY SERVICES ACTIVE IN TODAY'S GLOBAL MARKETPLACE

Today, numerous offerings and business models constitute shared mobility, and this market is growing rapidly. The following interpretations of shared mobility are playing important roles in increasing the adoption of shared mobility around the world. While these business models differ, they all rely on a shift from ownership to usership. These solutions for two-, three-, and four-wheelers improve other means of sharing, especially public transport, and multimodal integration.

- **Intermediary services:**
  Intermediary services are regulated or unregulated mobility services that lie outside the range of public transportation agencies and typically travel flexible routes based on demand. In Indian cities with populations between 1 and 10 million people, three-wheelers, a popular form of intermediary services, make up 11% of the mode share. [21] . Autorickshaws and electric rickshaws provide first- and last-mile solutions in these cities. Opportunities may exist to extend the intermediary services market to two-wheelers, which make up 23% of the mode share in these cities,[22] and to digitize this market by developing protocols and platforms for data sharing that enable digital ride-hailing.

- **Ride-hailing services:**
  Ride-hailing services are data-enabled mobility services that allow travelers to hail private, point-to-point rides on an as-needed basis. These rides are generally longer in distance than those covered by intermediary services. Cities with populations greater than 2 million are generally strong candidates for four-wheel ride-hailing services, like TNCs, and public transit, including buses and metros, because the average trip length is greater than 5 km [23]. TNCs could capture as much as 16% of India's vehicle-kilometers traveled (VKT) by 2018,[24] creating an attractive avenue for fleet electrification due to their drivers' high utilization rates. While public buses, which account for over 20% of the mode share in cities with populations over 10 million, present another important entry point to electrification, electric buses may require more time to become economic.

- **Pooled ride-hailing services:**
  Pooled ride-hailing services are the same as ride-hailing services except that they are public, pooled rides that pickup and drop off multiple passengers along a constantly evolving route. Pooling creates a marketplace for "seat-kilometers," with vehicles carrying multiple passengers. A study from the Massachusetts Institute of Technology (discussed in detail in Section 2) found that 3,000 four-person vehicles could serve 98% of passenger-mobility demand, replacing 15,000 single-occupant taxis, with an average waiting time of 3.5 minutes [25]. Since launching in India in September 2015, UberPOOL has saved over 32 million VKT, 15 lakh liters of fuel, and 35 lakh kilograms (kg) of carbon dioxide (CO_2)[26]. Permitting TNCs' driver-owned fleets to operate with stage-carriage permits, as opposed to contract-carriage permits, across all Indian states could rapidly grow this market offering and thus encourage widespread fleet electrification.

- **Vehicle sharing:**
  Vehicle sharing is an alternative to private-vehicle ownership. Vehicle sharing companies allow customers to access the vehicles that they want when they need them. For example, Zipcar has over 730,000 members who reserve and use 11,000 cars by the hour [27]. ZipCar achieves a 30–40% asset utilization rate [28]—6 to 8 times higher than that of a privately owned vehicle. Car2go, owned by Daimler, is the world-leader in one-way car sharing, where users can book a vehicle and pay US$0.41 per minute [29]. Scoot, based in San Francisco, U.S., has 700 electric scooters (manufactured by Mahindra) that users can pick up and drop off anywhere in the city [30]. Vehicle-sharing networks of various designs can provide transport 4 to 10 times cheaper than driving a privately owned vehicle [31]. This model of usership could allow Indian citizens to access the vehicles they want, when they want them, without perpetuating the costly paradigm of ownership.

- **Peer-to-peer vehicle sharing:**
  Peer-to-peer vehicle sharing is part of an emerging trend of the sharing economy, in which consumers are able to rent vehicles from their neighbors or peers. Getaround is one such business that allows customers to rent vehicles by the hour or day directly from their peers, who in some cases have earned up to US$10,000 per year by placing their vehicles on the Getaround platform. Getaround rentals include insurance and 24-hour roadside assistance [32]. This model of sharing could increase privately owned vehicles' asset utilization rates.

- **Fixed-route commuter services:**
  Fixed-route commuter services target commuters, who represent a large portion of total weekday trips. Commuter services are a significant opportunity for displacing

single-occupant vehicles with shared mobility. Chariot, a U.S.-based company, crowdsources commuter routes and delivers employees to work using minibuses and optimized routes for about US$4 per commute [33]. Lithium, a Bangalore-based company, offers electric mobility services for commuters, and has quickly scaled from 10 to 200 EVs, covering 60,000 electric VKT daily [34].

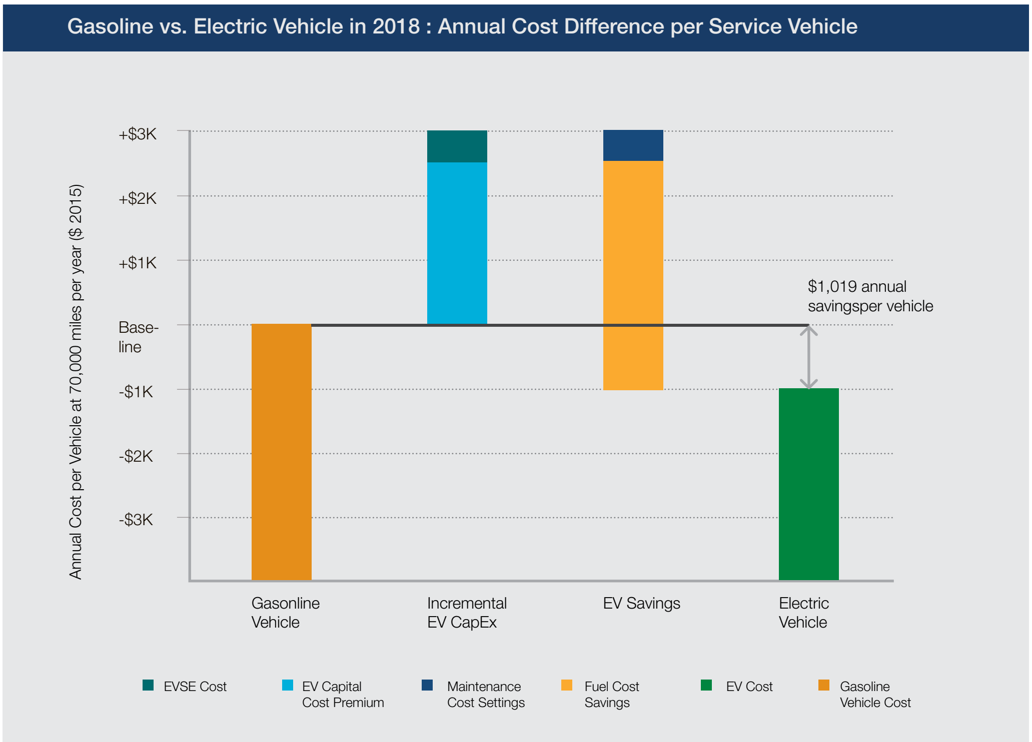


Figure 5. The relative economics of high-mileage EVs vs. ICEs shows that high-mileage EVs' will benefit from an approximately $1,000 annual cost advantage in 2018. Source: RMI, Peak Car Ownership, 2016

The rapid growth of the sharing economy and mobility services will help drive adoption of EVs in high-utilization service fleets. Mobility service providers around the world are already testing EV solutions in pilot programs in anticipation of global deployment [35,36]. Compelling economics are also encouraging drivers on TNC platforms to take advantage of EVs' lower O&M costs, which in high-mileage applications offset their upfront capital cost premium in a few years or less and can produce $1,000 and $4,000 in annual savings by 2018 and 2030, respectively (please see Figure 5) [37]. With private-vehicle ownership growing at a 10% compound annual growth rate, India will need to add a lane to every national highway every three years to accommodate these new vehicles, reinforcing the need for shared mobility in India.

These applications of sharing may also support job growth, as well as higher utilization of and greater investment in India's non-motorized and public transit infrastructure. By providing critical first- and last-mile solutions, as well as avenues for introducing advanced data solutions, shared EVs have the potential to help preserve India's high share of walking and biking while driving demand toward efficient, high-load modes of public transit, especially buses and metros. Government and business leaders should explore collaborative opportunities to create integrated transport hubs that provide seamless connectivity, better service delivery, and greater access at lower cost.

2.3 INCENTIVES TO PROMOTE ELECTRIC MOBILITY AND SHARING

Despite compelling economics, persistent challenges exist in the adoption of shared, electric mobility services. These challenges include operational mandates of service vehicles, risk aversion from drivers and fleet operators, and the first-cost difference between EVs and ICEs. Incentives have helped drive higher rates of EV penetration in other countries—without costing their governments much money to implement. Many of these low-cost incentives can also promote shared transportation over private-vehicle ownership with the appropriate design.

- **Parking and pick-up benefits:**
Parking benefits include discounted and designated parking spots in central locations. For example, a tiered rate structure could prioritize commercial and shared vehicles over privately owned, single-occupant vehicles. Pick-up benefits could include preferred pick-up locations for EV fleet and service vehicles, encouraging passengers to choose EVs out of convenience and service providers to switch to EVs for customer access. These preferred pick-up locations could be at transport hubs, like airports and train stations, and in highly trafficked urban areas.

- **Road toll and road tax discount or exemption:**
Shared vehicles could be exempt from paying states' road taxes and/or tolls for roads, bridges, or ferries, while privately owned EVs could have reduced taxes or tolls relative to ICEs. This incentive has proven highly successful in Norway, where EVs do not pay road tolls or ferry fees. In the 2017 Norwegian EV owner survey, 62% of respondents included free toll roads and 49% included lower annual road taxes when asked why they bought an EV.

- **Licensing and registration benefits:**
Registration benefits for EVs include lower or no registration fees and a streamlined registration process, such as allowing EV owners, either private or commercial, to jump to the front of the registration queue or register through a separate, designated queue, rather than waiting for an extended period of time. Shared and commercial EVs could be given the most preferential treatment in the registration process (i.e., the lowest or no registration fees and the shortest wait times). Companies could be allowed to register batches of electric fleet vehicles altogether, rather than going through the process for each vehicle separately. There could also be a separate license category for commercial EV owners, with lower (or no) fees and a shorter licensing process.

- **Congestion pricing:**
Congestion pricing involves levying fees for using a road at different times of day, with the highest fees during the most congested times. Fees can be proportional to the number of occupants in the vehicle and the amount of emissions from a vehicle, to incentivize shared, clean vehicles. London, U.K., introduced a congestion fee in February 2003. 10 years after the congestion fee's introduction, traffic levels decreased by 10.2%, according to Transport for London [38]. Congestion pricing could be used in urban areas' centers, where congestion is generally worst and demand highest, so that consumers are motivated to use shared EVs to get to the most in-demand locations. India could leverage its world-renowned IT industry to leapfrog road tolls and move straight to real-time congestion pricing in some areas.

- **Low-emission zones:**
  Low-emission zones are areas with access restricted to cleaner vehicles, keeping out more polluting vehicles. In some low-emission zones, more polluting vehicles have to pay more if they enter the low-emission zone (similar to congestion pricing but based on a geography, rather than the time of day). Low-emission zones could be designed such that certain areas—for example, the most congested—permit only shared or commercial EVs, while other low-emission areas could permit all EVs.

2.4 OTHER KEYS FOR UNLOCKING INDIA'S SHARED, ELECTRIC, AND CONNECTED MOBILITY FUTURE

Shared mobility services are already common in India. However, enhancing them can support higher adoption. With 80% of all trips less than 10 km in cities like Mumbai and Hyderabad, electric fleet vehicles and public buses can reduce private-vehicle ownership and thus costly oil imports and emissions. By 2018, TNCs may travel over 65 billion VKT globally. Shared services could make more productive use of India's capital and reduce the number of vehicles on the road by nearly 6 crore in 2030, relative to business as usual, alleviating traffic congestion and local air pollution.

As battery costs continue to fall, the TCO of privately owned EVs in India—including purchase price, fuel and maintenance costs, and other expenses—will be lower than a comparable ICE in 2020 (please see Figure 6), a tipping point that will dramatically accelerate EV adoption. The economics of a shared, high-use EV sedan, however, are already favorable (please see Figure 7). These compelling economics are conservative, as they do not account for India's potential impact on global battery pack prices.

With estimates indicating that India's urban population will nearly double in the next decade, from 377 million in 2011 to approximately 600 million in 2030,[39] shared EVs represent a critical pathway for efficiently, cleanly, and safely mobilizing the citizens of India's cities. In addition to business-model innovation and incentives, many other pieces must be in place to encourage EV adoption. Interoperable transit data, a robust network of electric vehicle supply equipment (EVSE), and abundant, cheap batteries are also critical to EV adoption, as the next four sections will discuss.

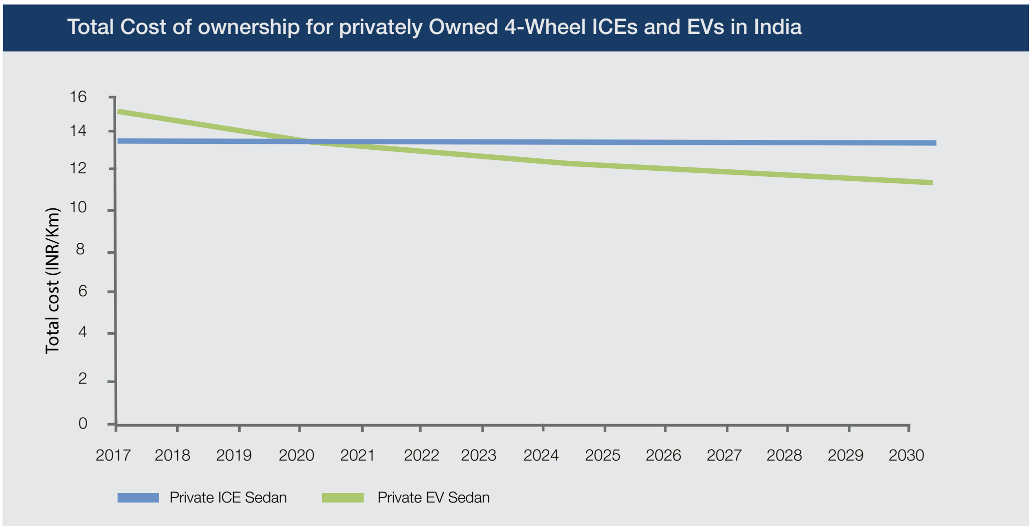


Figure 6. Privately owned EVs might be cheaper than comparable ICEs on a TCO basis in India by 2020.
Source: RMI analysis

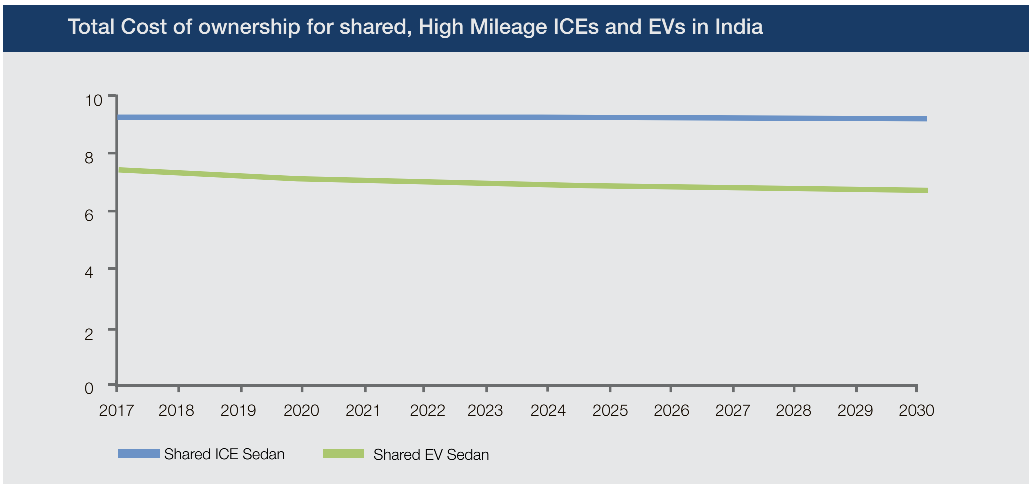


Figure 7. Shared, high-mileage EVs are already cheaper than comparable ICEs on a TCO basis in India. Source: RMI analysis

3 Interoperable Transit Data: Driving Shared Mobility Services

Key recommendations for shaping the way forward:
Build a national platform that makes interoperable transit data ubiquitous, enabling seamless and multimodal planning, booking, and payments. Prioritize data solutions for shared vehicles.

3.1 THE ROLE OF DATA IN SHARING AND MOBILITY SERVICES

Data ubiquity and connectivity are key enablers of shared mobility. Interoperable data can connect infrastructure, businesses, and users to expand transportation markets. The aggregation of commonly disparate data feeds can create a dramatically more efficient mobility system, leading to higher asset utilization rates and load factors across vehicle segments. Widespread data availability and use expands the market for mobility services by providing better visibility into supply and demand, creating more opportunities for optimizing driver-rider pairings. India will need appropriate data infrastructure and innovation to harness data's potential as a driver of shared mobility services.

3.2 QUANTIFYING THE IMPACT OF INTEROPERABLE TRANSIT DATA

There are many potential benefits of shared mobility, including higher asset utilization, lower VKT per passenger-km, and smaller vehicle fleets. Shared mobility, enabled by data solutions, can more efficiently meet India's growing transportation, helping alleviate costly traffic congestion, local air pollution, and global climate change. With mobile booking already allowing drivers to cover more than 1 lakh km per year, electrification offers drivers competitive advantage and could soon become the new norm in high-mileage applications.

Several researchers at the Massachusetts Institute of Technology (MIT) developed a model to understand the potential effects of shared mobility on New York City's passenger mobility system. Their results suggest that shared mobility, in the form of pooled ride-hailing, can provide quality mobility services while dramatically reducing the size of the fleet required to meet the city's transportation demand.

3.3 ABOUT THE NEW YORK CITY MODEL AND ITS IMPLICATIONS FOR INDIA

The MIT researchers developed a city-level model to analyze how ride-sharing, in a fleet of high-capacity vehicles, could meet historical, generally single-occupant taxi demand in New York City (NYC) [40]. Operating in real-time, the model dynamically pairs drivers and riders and optimally routes trips, allowing for multiple pickups and drop-offs in a trip without breaking defined quality of service constraints (e.g., maximum waiting time and in-trip delay). The model relocates unoccupied vehicles to high-demand areas in order to improve service. This model is scalable to real-world applications for a few reasons:

- It is built on actual city-network maps.
- It uses real-world data as an input.
- It performs real-time driver-rider pairings and routing optimization.

In simulations, 3,000 four-seat vehicles were able to meet 98% of NYC's taxi demand, with an average pickup waiting time of 2.7 minutes and an average in-trip delay of 2.4 minutes. Originally, NYC required 13,000 taxis to meet this demand.

3.4 EXAMPLES OF DATA SOLUTIONS ACTIVE TODAY'S GLOBAL MARKETPLACE

Many examples of data solutions and pilot programs offer insights into how India can consider developing transit data standards and infrastructure that enable data interoperability and thus sharing and economic fleet electrification. The following examples of high-quality transit data solutions illustrate how data standards, transparency, accessibility, and innovation can increase the adoption of shared mobility.

- **Data standards:**
  Established in 2006, the General Transit Feed Specification (GTFS) defines a common format for fixed-route public transit information, facilitating how these data import into transit-routing applications built by developers [41]. A GTFS feed includes information on stops, routes, trips, and other data (e.g., fares). Globally, there are over 400 GTFS feeds [42]. In 2010, estimates suggest that 85% of all transit miles in the U.S. were on transit systems with open data [43]. As other shared modes of transportation gain traction, including car sharing and bike sharing, more standards are developing. As India seeks to increase sharing, creating standards will be an important first step in making transit data available. Such standards serve to improve data quality and interoperability.

- **Data transparency:**
  Many TNCs are now offering pooled ride-hailing options and piloting EVs, testing business models for sharing and fleet electrification in urban markets. Although TNCs operate on custom platforms, opportunities exist to increase both transparency and quality of service—key drivers of user adoption. If India's pooled ride-hailing market expands, fleet electrification will become a major business opportunity and a competitive advantage for TNCs and their drivers. UberPOOL is seeing rapid growth since launching in Bengaluru in September 2015. It has expanded to Delhi, Hyderabad, Kolkata, Mumbai, and Chennai, and UberPOOL rides account for over 30% of Delhi's Uber rides and over 20% of Uber rides in the other five cities [44].

- ## Mobile booking:

  TNCs provide on-demand, passenger-based mobility by using digital platforms to pair riders with drivers. These ride-hailing services work by pairing a single trip request, from point A to point B, with an available vehicle. Over the past few years, these TNCs have started offering pooled ride-hailing. Sharing allows riders traveling in the same direction to share a vehicle with additional riders traveling along a similar route, reducing fares for all riders. Mobile booking, high-resolution maps, and data algorithms that optimize driver-rider pairings in real-time make this pooled ride-hailing solution possible.

- ## Data Aggregation and Innovation:

  Although standards may lay the foundation for sharing, it is aggregators who create comprehensive data sets from feeds, linking available transportation modes, costs, traffic, even weather to map a complete system and thus improve usability. Examples of data aggregators include 511.org, Apple Maps, Google Maps, and Open Trip Planner. These aggregators increase user awareness by displaying vast quantities of up-to-date (ideally real-time) information side-by-side in a digestible format. The future of usability is in providing a user-friendly digital interface that integrates routing, booking, and payment to facilitate sharing and integrate across modes and with related infrastructure (e.g., parking, shopping, attractions, etc.). Giving users transparency, choice, and access to a one-stop mobility marketplace can help more efficiently meet their transportation needs.

  One example of putting many of the pieces together is Moovel by Daimler. Launched in April 2016, Moovel integrates routing, booking, and payment across many modes, including public transit, vehicle sharing (car2go), taxi services (mytaxi), and trains[45]. Moovel is partnering with the city of Hamburg, Germany to integrate the city's modes of transportation and launch both EV fleets, including buses, and charging infrastructure. This initiative will potentially not only raise the global bar for sharing and multimodal integration, but also for fleet electrification[46].

  Data help create larger networks of riders and drivers—and thus more opportunities to fill empty seats. Interoperable transport data is a key driver of sharing and mobility services, which in turn unlock economic fleet electrification. A broad portfolio of incentives and a supportive ecosystem, including charging infrastructure and swappable battery stations, are also critical to enabling vehicle electrification across India. How successfully these policies and systems integrate in support of India's vision for a shared, electric, and connected mobility future will rely heavily on the data that connects them.

4 EV Charging Infrastructure: Powering EVs and Recharging India's Electricity Sector

Key recommendations for shaping the way forward:

Invest immediately in a dense EV charging infrastructure network to support the rapid penetration of EVs, as well as renewable energy integration, and to create new value streams for the electricity sector. Value the potential grid services provided by EVs.

4.1 INDIA'S MOBILITY AND ELECTRICITY SECTORS CAN CREATE MORE VALUE TOGETHER

India's vision of leapfrogging the traditional passenger mobility system to one that is shared, electric, and connected has many implications for India's electricity sector. As the barriers to EV adoption begin to fall, one major barrier remains: the lack of EV charging infrastructure. While filling this gap is potentially the greatest challenge to EV adoption in India and globally, successfully deploying and scaling EV charging infrastructure also represents one of the biggest enablers of the EV revolution. Strategic planning can help cost-effectively deploy EV charging infrastructure for powering India's EV fleet, while providing multiple benefits for India's rapidly changing electric grid through vehicle-grid integration (VGI). Successfully integrating variable renewables into India's electric grid can meet a variety of economic and climate goals, from job creation to decarbonization, by continuing to support record-breaking solar PV prices in India [47].

4.2 THE NEED FOR DEPLOYING AND SCALING EV CHARGING INFRASTRUCTURE IN INDIA

Governments and private-sector players around the world are beginning to realize that they must develop dense EV charging infrastructure networks to accelerate EV adoption. Ubiquitous EV charging infrastructure will help create virtuous cycles of adoption: higher deployment and utilization of charging infrastructure will create economies of scale in manufacturing and new markets for the grid services that EVs can provide, leading to even higher deployment and utilization rates. While critics often point to the "chicken-and-egg" problem—the need for ample EV penetration as a prerequisite for EV charging infrastructure deployment vs. the need for abundant EV charging infrastructure as a prerequisite for EV adoption—as a problem without a solution, a new U.S. analysis confirms that availability and accessibility of reliable public charging infrastructure must precede dense EV penetration [48]. With steeply falling technology costs, new business models, and increasing consumer awareness indicating that EV adoption will grow rapidly in the coming years, deploying and scaling EV charging infrastructure in the near-term will be critical to supporting this emerging market.

The deployment and scaling of EV charging infrastructure in India will be a monumental undertaking given India's size, complex policy and regulatory environment, and weak electricity distribution infrastructure. India must rapidly and widely deploy public charging infrastructure in order to achieve its target of 100% EVs, in terms of sales, by 2030. With only 222 community EV charging stations in the entire country, this objective is indeed a significant undertaking [49]. However, engagement and alignment among private-sector players, utilities, and governments at all levels, coupled with clarity of intention and strategy, can help India realize its mobility leapfrog.

Multiple government and private-sector entities have thrown their hats in the ring, upping their contributions in support of the Indian government's ambitions. A TNC recently started an EV pilot in India with centralized charging infrastructure, including conventional charging and swappable battery infrastructure [50]. India's largest generating utility, NTPC, announced plans to enter the EV charging infrastructure market and develop charging infrastructure in the Indian cities of Delhi and Noida [51]. Most recently, EESL invited bids for 4,000 charging stations in the National Capital Region [52].

4.3 EXAMPLES OF EV CHARGING INFRASTRUCTURE ACTIVE IN TODAY'S GLOBAL MARKETPLACE

- **Norway**

Nowhere in the world are EVs a higher share of passenger vehicle sales than Norway. Norway's government has generally been highly supportive of EV adoption, declaring a goal of reaching 100% EVs, in terms of new vehicle sales, by 2025. Through September 2017, plug-in hybrid electric vehicles (PHEVs) and battery-electric vehicles (BEVs) made up 36% of Norway's passenger vehicle sales [53]. A history of supportive policies and investment in a network of charging infrastructure has been a key enabler of Norway's transition to EV technology [54]. A report by the Norwegian EV Association notes that "initial support" was "crucial" in developing the country's EV charging infrastructure network and cites this well-designed charging network as a key enabler of Norway's mass-market EV adoption.

By the numbers:

- Norway has 8,654 publicly accessible charging points, with mostly Schuko plugs [55].
- There are 569 fast/semi-fast charging stations across Norway [56].
- The majority of Norwegian EV owners (~75%) charge at home on a daily basis [57].
- Around 60% of Norwegian EV owners charge at fast charging stations on a monthly basis [58].

Between 2010 and 2014, the Norwegian government provided around INR 40 lakh in funding for fast chargers, with up to 100% support for installation costs but no support for operating costs. While operators largely selected the location for fast chargers, the government prioritized some locations for funding. Starting in 2015, Enova, a state-owned enterprise, put out public tenders for a national fast-charging network, seeking to deploy double multi-standard fast-charging stations every 50 km on all main roads in Norway. Enova successfully completed this project by the end of 2017.

Considering the differences between India and Norway—in terms of population size and density, gross domestic product per capita, geographical area, and climate, to name a few examples—there are some limitations as to what India can learn from Norway's model. For example, since India probably has fewer per-capita funds to devote to subsidies for the deployment of EV charging infrastructure, the country will probably have to explore innovative business models and partnerships to help finance this deployment. As another example, considering the significant difference in population density (15 people per km2 in Norway vs. 450 people per km2 in India), India will probably want to prioritize EV charging infrastructure for shared vehicles over that for privately owned vehicles.

4.4 MAXIMIZING THE BENEFIT OF EV CHARGING THROUGH VGI

According to analysis from Lawrence Berkeley National Labs, meeting India's EV goals would have a relatively minor impact on its electricity demand, adding about 6% (23 GW) to its projected peak and about 3% (82 TWh/year) to total electrical energy demand. This additional load represents a significant financial opportunity for India's distribution companies (DISCOMs). The study estimates that EV owners' total expenditure on EV charging could be nearly US$11 billion (INR 70,000 crore) per year by 2030 [59].

Managing this growing electricity demand could have make-or-break consequences for India's already distressed electric grid. India's DISCOMS have a total debt of about INR 4.3 lakh crore, with annual losses on the order of INR 89,000 crore [60,61]. Appropriate management of the additional load EVs will create could not only help smooth the grid's load shape, potentially avoiding costs of new generation equipment and new transmission and distribution infrastructure, but also deliver valuable grid services (e.g., renewable energy integration) and provide utilities with a much-needed revenue stream.

Mismanagement of this additional load, however, could increase stress on existing distribution assets, potentially crippling India's EV ambitions. Alignment among EVSE developers and utilities on charging infrastructure requirements, the siting of this charging infrastructure, and appropriate tariff structures will be critical to economic deployment and use. A well-coordinated EVSE deployment plan that incentivizes vehicle charging at the right time and place, based on local grid conditions and the type of generation resources, will be critical to the successful development of India's EV charging infrastructure network. For example, incentivizing EV charging at times when there is excess solar generation on the grid through lower time-of-use rates could help sunny regions reduce curtailment during midday solar over-generation. As another example, smart devices in chargers that respond to changing tariff structures could enable controlled and coordinated EV charging. Utilities could set tariffs that incentivize behaviors that reduce the cost of charging for the EV owner and provide multiple grid benefits (peak shaving, demand response, ancillary services, etc.). Regulators could allow EV owners to monetize these benefits, creating an incentive for EV adoption.

4.5 CONSIDERATIONS AND IMPLICATIONS FOR INDIA'S EV CHARGING INFRASTRUCTURE DEPLOYMENT

As EV adoption in India is still at an early stage, policymakers and EV manufacturers have an opportunity to get out in front of and thus support coordinated EV charging infrastructure deployment. A fragmented system of standards in the U.S. has reduced EV adoption and resulted in scattered infrastructure investment [62]. Fortunately, the Government of India's Department of Heavy Industries has already initiated a process to address this common issue [63].

Deployment of public charging infrastructure for sequentially economically viable market segments can ensure growth of EV charging infrastructure in lockstep with the growth of EVs. This strategy implies that EV charging infrastructure should prioritize infrastructure for scooters and three-wheelers first, through a combination of conventional charging and battery swapping infrastructure, followed by public charging infrastructure for shared four-wheel vehicles, private four-wheel cars, and buses. There is tremendous potential for India to manufacture this hardware in India.

Studies from other regions with high EV penetration indicate that the geographical distribution of EVs highly correlates with the density of EV charging infrastructure [64]. EV adoption in some cities drops precipitously outside the dense metropolitan center, where charging infrastructure is often scarce. To avoid this common mistake and thus encourage EV adoption and use, Indian cities may consider meeting a large portion of total charging demand through public charging infrastructure due to space, cost, and grid constraints. Initial modeling of Delhi's EV charging infrastructure, at low levels of EV penetration, suggests that "the spatial distribution of chargers roughly parallels the level of traffic intensity and density of places of employment in the metropolitan region of Delhi, with the highest concentration of chargers occurring near the city center and the lowest concentrations occurring in the outlying regions [65]." While no studies model EV charging infrastructure requirements at penetration levels close to India's stated goal of 100% EV adoption by 2030, a similar pattern will probably persist. India will also require EV charging infrastructure along major interstate highways to support long-distance travelers driving to and from urban centers.

Encouraging competition in the EV charging infrastructure market can lead to a healthy, dynamic market. In the U.S. and elsewhere, Tesla has already built a large network of superchargers. Other vehicle manufacturers, such as Volkswagen, are now competing to enter this market. Other solution providers—including ChargePoint, EVgo, and several California utilities—are also vying for market share. To meet its 2030 target, standards, coordinated action across India's public and private sectors, and an open, competitive market for EV charging infrastructure development will help accelerate deployment and thus stimulate EV adoption.

5 Swappable Batteries: Cutting Upfront Costs and Complementing EV Charging Infrastructure

Key recommendations for shaping the way forward:
Apply the battery-swapping model to specific vehicle segments and applications that are unique to the Indian market (e.g., two- and three-wheelers) to reduce challenges associated with first-cost bias, range, and charge time.

5.1 WHERE BATTERY SWAPPING COMES INTO PLAY

To overcome some of the difficulties of developing private charging infrastructure and the high first-cost of EVs, the Government of India is planning on an EV ecosystem in which vehicles will be sold without their most expensive component: batteries[66]. These batteries will be charged outside the vehicle at centralized locations, then "swapped-in" as vehicles arrive with depleted batteries.

Designing and manufacturing swappable, standardized batteries has a number of advantages. One, swappable batteries can reduce the upfront cost of EVs by removing the battery from the initial capital cost, making EV prices near or equal to comparable ICEs. Two, the use of swappable batteries alleviates potential customer concerns about range anxiety and charging times. Three, the use of swappable batteries is a benefit to the grid because it helps consolidate charging stations, allowing them to operate in coordination with the grid as opposed to running in a decentralized fashion at the whim of customers charging at home.

Two-wheelers—at 180 million and growing—will play a considerable role in India's EV future. While it appears that swappable batteries will initially be deployed in three-wheelers and potentially buses, industry experts think that scooters and motorbikes could also be viable candidates based on favorable economics and design applicability [67]. Providing access to swappable battery stations could alleviate concerns for many two-wheeler owners, who probably do not have access to private charging stations due to space or monetary constraints.

5.2 EXAMPLES OF BATTERY SWAPPING ACTIVE IN TODAY'S GLOBAL MARKETPLACE

- **Better Place:**
Better Place, an Israeli company, partnered with Renault to design an automobile with a small, 120-km range battery system designed for swapping. Customers could

charge the vehicle at home using charge systems or stop by one of Better Place's swapping stations while on the road to swap a depleted battery. Because the system relied on massive sales of the Renault vehicles, which used the swappable battery system Better Place had developed, the model failed when initial plans called for 100,000 of these vehicles and only 1,500 were sold. There was not enough demand for the vehicle, which had a high (US$38,000 or INR 25 lakh) price tag. With limited demand for the Renault vehicle, the battery leasing program, or the swapping stations, the company eventually failed.

Better Place's failure shows that markets for swapping stations and EVs go hand in hand, and that a certain level of EV acceptance and penetration must precede the swapping model. Swapping stations can survive with lower use, but only after a certain amount of the EV market exists. Swappable batteries should be standardized across more than one vehicle model; otherwise they become too vulnerable to consumer preferences. In order for the swapping model to successfully scale in India, the standardization of batteries and vehicles will be essential, as will coordinated planning with electric utilities.

- **Gogoro:**
  Evidence of the viability of the swappable battery model is also creeping up in other geographies, especially when the model targets vehicle segments with favorable economics. Gogoro, a company making scooters with swappable batteries, has reportedly raised US$500 million and deployed 400 battery-swapping stations in Taiwan, where users swap 17,000 batteries daily. Gogoro is also building a network of kiosks in the region that lets customers swap used batteries with charged ones. The company is planning on expanding to the U.S. and E.U

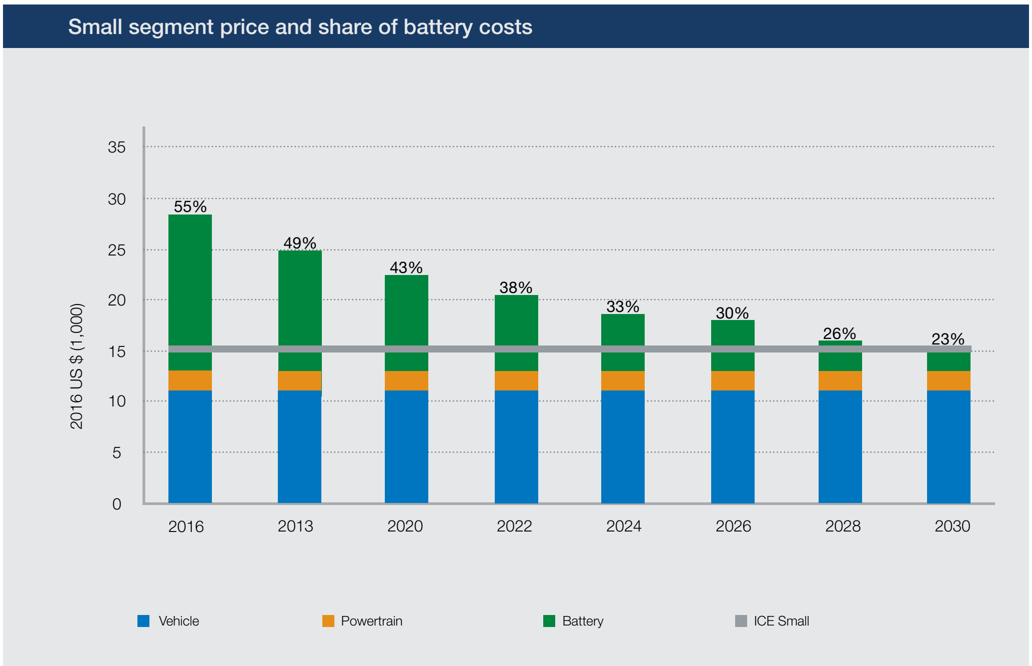


Figure 8. Batteries currently make up over half of the capital cost stack of EVs. While industry analysts expect batteries' share of and the total capital cost of EVs to come down over time, battery swapping can make some vehicle segments economic today. Source: Bloomberg New Energy Finance [68]

5.3 THE ECONOMICS OF SWAPPABLE BATTERIES

The higher upfront cost of EVs is a primary barrier to deployment in India. BNEF analysis finds that in small vehicles, batteries contribute to more than 50% of EVs' upfront cost (please see Figure 8). Shifting towards smaller, leased batteries and using a swapping business model means EV operating costs are spread out over the lifetime of the vehicle rather than paid for at the point of purchase. If ICE drivers had to pay 20 years of fuel costs upfront, it would certainly influence consumer preferences. When EV drivers pay for batteries as they use them over the vehicle's lifetime, rather than upfront, this payment structure makes the initial purchase price of EVs equivalent or lower than comparable ICEs. Battery-swapping business models also allow higher turnover of batteries towards newer models, increasing efficiency and decreasing costs.

The widespread adoption of battery swapping networks can make range anxiety a thing of the past. Most private vehicles do not drive more than 30 km/day, but drivers demand larger batteries because they worry their charge will run out during the day (even if this scenario is highly unlikely given conventional urban driving patterns). Users do not want to incur the loss of time or (if operating a driving service) revenue associated with waiting at a charging station. With swapping stations available, swappable batteries can unlock the economics of certain market segments, especially two- and three-wheelers. The availability of battery swapping stations means EVs can travel as far as necessary, eliminating a behavioral barrier to deployment. The only sacrifice is absolute range: swappable batteries are generally smaller sized in order to reduce their weight and make swapping feasible. This dilemma is not a concern in urban environments, where travel distances are short and swapping stations can be conveniently placed.

Unlike charging infrastructure, there is no large load on the electric grid as vehicles rush to fast charge. Batteries charge in advance and, with smart metering, companies offering swappable batteries can charge at times that are most convenient to the electric grid, creating a reliable demand source for utilities to balance generation against. Rather than hundreds of thousands of users plugging into high-speed charging networks immediately upon leaving work—a difficult load on any network—batteries charged by a centralized authority could best meet consumers' needs while benefitting the larger electrical system. This smart tracking also allows for a better understanding of when charging is happening and when needs will be greatest.

Business models explored by Professor Ashok Jhunjhunwala found that all these aims could be achieved for less than the cost of diesel per km, while achieving a 20% margin for the business. These attractive economics are in addition to completely eliminating the upfront cost of the vehicle's battery. Studies of per-km operating costs for EVs have already found that EVs are less expensive than ICEs on a per-km basis; their only disadvantage is that many of their upfront capital costs are front-loaded. Battery swapping avoids this issue of higher upfront cost [69].

In short, battery swapping allows drivers to use a potentially pollution-free vehicle, with lower fuel costs, that costs less upfront than their current one. Battery swapping opens up a new market for EVs, as it potentially makes them the most cost-effective option today, rather than in a few years as battery costs decrease. Together, EV charging infrastructure and swappable batteries present a collective opportunity for India to innovatively and cost-effectively charge its soon-to-be expanding fleet of EVs, creating shared value for the country's mobility and electricity sectors.

6 Battery Manufacturing: Making EV Components in India

Key recommendations for shaping the way forward:
Set up a manufacturing consortium on batteries and EV components, and begin building a battery pack assembly industry immediately, in support of the Make in India initiative. Make selective investments in cell manufacturing over time as new battery chemistries mature. Start-up incentives can be used to de-risk early stage investments in battery manufacturing and accelerate the development of India's domestic battery manufacturing industry.

6.1 THE ECONOMIC OPPORTUNITY OF A DOMESTIC BATTERY MANUFACTURING INDUSTRY IN INDIA

India's goal to reach 100% EV sales by 2030 represents a major opportunity for its domestic manufacturing industry. Domestic manufacturing of batteries, which currently represent one-third or more of most EVs' upfront capital cost, is a major economic opportunity for India. Developing battery manufacturing expertise and scaling domestic production capacity can build durable economic advantage for the country.

Modeling indicates that India will require at least 800 GWh of batteries per year in order to meet the demands of a 100% EV market. Given the projected scale of its domestic market, India could support global-scale manufacturing facilities and eventually become an export hub for battery production. 25–40% of the total economic opportunity represented by battery manufacturing for India's EV ambitions can be captured in India, even under the least favorable scenario where India imports all Lithium-ion cells and assembles battery packs (please see Figure 9). As India's capabilities mature and supply chains develop, India has the opportunity to manufacture both battery cells and battery packs, while importing only the cathode or its raw materials from mineral-rich regions. In this scenario, India stands to capture nearly 80% of the total economic opportunity presented by domestic battery manufacturing.

Global battery manufacturing capacity continues to increase significantly, with many companies and nations announcing plans to build more gigafactory-scale plants in the future. Prior to the announcement of India's EV target, industry analysts estimated that global demand for EV batteries would hit 1,300 GWh/y by 2030. Taking into account India's announcement and the expectation that India will need 800 GWh/y of batteries by 2030 would increase this market projection by 60%. It would also make India one of the largest markets for EV batteries in the world.

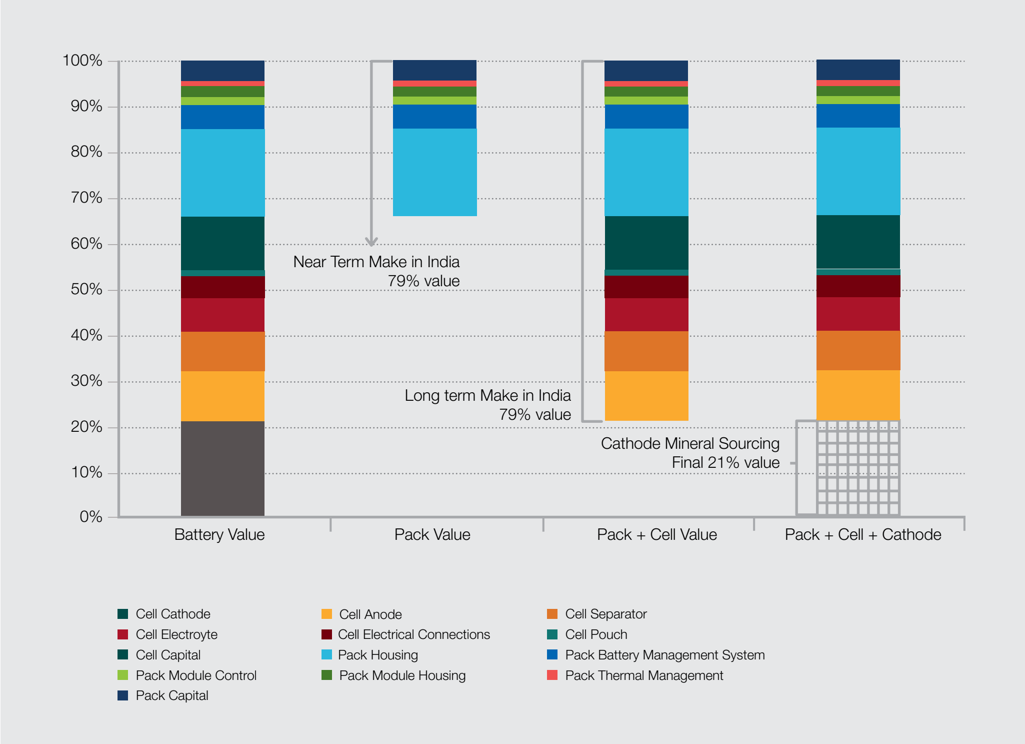


Figure 9. India can quickly capture 25–40% of component production cost of Lithium-ion batteries by assembling packs in India. It could capture almost 80% of this value over time. Source: Bloomberg New Energy Finance, Bottom-Up Cost Scenarios for Li-ion Batteries [70], February 2017, and NITI Aayog and RMI analysis

Global battery manufacturing capacity continues to increase significantly, with many companies and nations announcing plans to build more gigafactory-scale plants in the future. Prior to the announcement of India's EV target, industry analysts estimated that global demand for EV batteries would hit 1,300 GWh/y by 2030 [71]. Taking into account India's announcement and the expectation that India will need 800 GWh/y of batteries by 2030 would increase this market projection by 60%. It would also make India one of the largest markets for EV batteries in the world.

6.2 POTENTIAL SAVINGS COMPARED TO OIL IMPORTS

India's switch to batteries is both a market growth opportunity and a potential market savings opportunity. Given current utilization trends, India would require nearly 1,600 million metric tonnes oil equivalent of petrol and diesel to fuel its passenger mobility sector between 2017 and 2030. Assuming India continues to import nearly 80% of its oil, this oil-import demand could cost US$550 billion (INR 36 lakh crore).

By contrast, meeting India's EV ambitions through 100% domestic manufacturing of batteries would require at least 3,500 GWh of batteries between 2017 and 2030, at a wholesale cost of US$300 billion (INR 20 lakh crore)—half the cost of the avoided oil imports. In addition, battery manufacturers could seize 25–40% of the market's value at the onset by assembling battery packs in India and importing only the cells. Thus, India can both save money and create a domestic industry to generate additional value for its economy by shifting to an electric mobility future.

6.3 POTENTIAL SAVINGS COMPARED TO OIL IMPORTS

The major challenges India faces to battery manufacturing growth are:

- **Low domestic reserves of minerals**
  - Limited reserves of lithium, cobalt, nickel, and copper that are primary constituents of current battery chemistries

- High import dependency

- **Early stage battery manufacturing industry**
  - Absence of EV battery manufacturers and lack of state-of-the-art facilities, in terms of capacity and capability

- **Fragmented efforts by key stakeholders**
  - Fragmented efforts by key stakeholders like vehicle and battery manufacturers, governments, research institutes, and think tanks

- **High perceived risk**
  - Perceived risk in investing resources, money, and efforts by early adopters

This report recommends establishing a multi-stakeholder research and development consortium that includes members from the government, battery manufacturers, vehicle manufacturers, scientists, and other leading thought leaders. Similar consortia are trying to address similar problems in other parts of the world, including in the U.K. and E.U. For example, the Business Secretary of U.K. government recently announced a consortium, the Faraday Battery Institute, that will bring together experts from seven founding partner universities and industry [72].The main goal of this consortium, which has US$86 million (INR 560 lakh) behind it, is to foster innovative, collaborative research between world-leading universities and businesses to make battery technology more accessible and more affordable.

By building a consortium to create unified action and strategies, investing in research and development, and lowering risks to first movers through incentives, India can overcome these barriers. Domestic manufacturing of batteries and EV components could help OEMs and technology companies capitalize on aggressive vehicle electrification goals within India, while bolstering job growth at home and India's competitiveness on the global stage. Indigenously developed electric vehicle platforms and solutions that are readily adaptable to Indian use-cases could be applicable in other developing economies. In the long run, Indian OEMs could not only cater to the domestic market, but also capture a significant share of the global EV market.

Together, EV charging infrastructure and swappable batteries present a collective opportunity for India to innovatively and cost-effectively charge its soon-to-be expanding fleet of EVs, creating shared value for the country's mobility and electricity sectors.

Conclusion

There are many barriers to EV adoption in India and around the world. Sharing and mobility services help unlock the superior economics of high-mileage EVs through a variety of innovative business models, reducing concerns about cost. Interoperable transport data helps enable this sharing and these mobility services, putting more people in fewer vehicles and thus optimizing system efficiency, increasing access and affordability, and improving service quality and safety. EV charging infrastructure and battery swapping can work together to power these EVs, both privately owned and shared, reducing concerns about range anxiety while providing valuable benefits and opportunities to India's electricity sector. Domestic battery manufacturing helps bring down the upfront cost of EVs, reduces India's dependence on foreign oil, and supports India's ambitions for job creation and industrial growth.

In light of global context and India's unique conditions, the following suggestions will create business opportunities and speed India's transition to shared electric mobility.

Key recommendations for the way forward:

- **Sharing and mobility services:**
  Target shared and fleet vehicles— including two-wheelers, three-wheelers, and government fleets—for immediate electrification given their favorable economics. Introduce policies and incentives that further encourage sharing and electrification, especially in intermediate and public transport applications.

- **Interoperable transit data:**
  Build a platform that makes interoperable data ubiquitous, enabling seamless and multimodal planning, booking, and payments.

- **EV charging infrastructure:**
  Invest immediately in EV charging infrastructure to support the rapid penetration of EVs, as well as renewable energy integration, and to create new value streams for the electricity sector. Value the potential grid services provided by EVs.

- **Battery swapping:**
  Apply the battery-swapping model to specific vehicle segments and applications that are unique to the Indian market to reduce challenges associated with first-cost bias, range, and charge time.

- **Battery manufacturing:**
  Set up a manufacturing consortium on batteries and EV components, and begin building a battery pack assembly industry immediately, in support of the Make in India initiative. Make selective investments in cell manufacturing over time as new battery chemistries mature. Start-up incentives can be used to de-risk early stage investments in battery manufacturing and accelerate the development of India's domestic battery manufacturing industry.

India's passenger mobility is a complex system, and there are many barriers that will influence India's ability to achieve its ambitious goals. Together, the opportunities discussed in this report address some of the key barriers to EV adoption in India.

While these opportunities all require different solutions and will individually play important roles in increasing EV adoption in India, the integration of these solutions, supported by close collaboration and coordinated action across all of India's stakeholders, is critical to realizing India's shared, electric, and connected mobility future. This report aspires to encourage all Indian stakeholders to consider not only how their solution can contribute to this vision, but also how they can work together across different parts of the mobility system to collectively create more value for all Indians.

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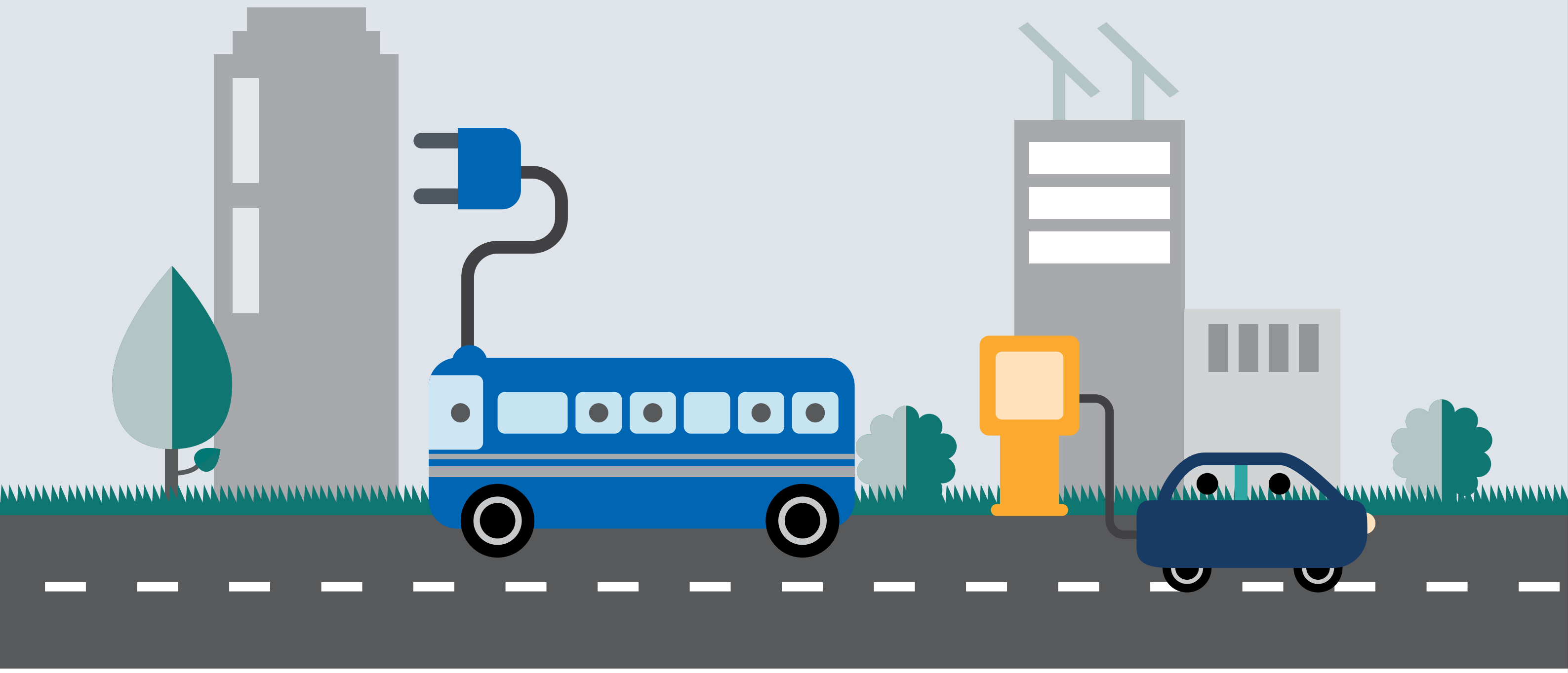

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