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Adapting to electric vehicles value chain in India: The MSME perspective

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ABSTRACT

India has committed itself to a greener and cleaner future by opting for the latest technological revolution in the world of Automotives – Electric Vehicles (EVs). However, the contribution of any technology to economic growth and environmental development is highly correlated with its extent of diffusion and adoption. While much has already been written about the EV ecosystem in the country and the electric market from a consumer standpoint, this paper analyses the supply-side challenges and opportunities in adapting to the electric mobility mission in India as perceived by the firms, especially the Micro, Small and Medium Enterprises (MSMEs). Using PLS-SEM method on data collected from these firms in the Indian automotive industry, this study finds that major factors that the firms feel are significant in adapting to the current disruption are financial, technological and regulatory in nature. The factors aiding the transition are the state and central policies while inputs and trade related factors are impediments due to excessive dependence on imports for raw materials, components and final goods. The paper has further employed the lens of value chain analysis to understand the dispersion of these across the various segments of the EV value chain.

1. Introduction

Electric Vehicles (EVs) are the next disruption in the world of Automotives which is supplanting a time-tested omnipresent technology – the Internal Combustion Engine (ICE). This revolution has accelerated in the backdrop of developments like climate change and sustainability (Paris Agreement, 2015; Sustainable Development Goals (SDGs) 2030), evolving consumer sentiments (more consciousness towards environment friendly cleaner fuels, intensifying regulations related to lowering per capita emissions), energy security (vagaries of oil supply and prices) and advancements in technology (digital technology, battery chemistry). India's journey towards its "green" goals has involved EVs adoption too. According to Ministry data, India has a total of 1.3 million EVs on the roads in 2022. As per a CEEW Centre for Energy Finance (CEEW-CEF) study, India is expected to be a $206 billion EV market by 2030 if it sustains steady progress. However, India is still an embryonic market as compared to the rest of the world as the current sales of EVs in India are meagre at 1% of the total vehicles sales as per the Society of Manufacturers of Electric Vehicles (SMEV).

Traditionally, India has always not only been a potential market but is also a major player in the automotive sector. From a global value chain perspective, India enjoys robust forward[1] (16.5%) and backward[2] GVC participation (19.8%), especially in transport equipment manufacturing. The Indian auto industry has strong manufacturing roots with a share of 74.8% domestic value added as a percentage of gross exports and 33.4% value added as a percentage of total production in 2018[3] while contributing 7% to India's overall GDP and 49% of the manufacturing GDP in 2021 (OECD TiVA Database). But similar performance in the EV segments manufacturing is yet to be witnessed.

As with any new technology, the transition and successful adoption of the disruption is based on a cascade of choices made by the stakeholders (consumers, manufacturers, governments, intergovernmental bodies etc.) related to the trade-off between the uncertain costs and unclear benefits vis-à-vis the new invention (Marra et al., 2003; Dyerson and Pilkington, 2005). Hence, the commercialization of any technology meets with supply-side, demand-end, infrastructural and institutional challenges (Parente and Prescott, 1994; Lee and Malerba, 2017). Despite the thrust by the Government (central and states), the uptake of electric

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[1] Domestic value added in foreign exports as a share of gross exports, by foreign exporting country, FEXDVApSH (c,p), represents the domestic value added from country c embodied in the gross exports of foreign country p, as a percentage of country c's total gross exports, EXGR (c). Calculated for total industry only.

[2] Foreign value added share of gross exports, by value added origin country, DEXFVApSH (c,p), represents the foreign value added from "partner" country p embodied in the gross exports of country c, as a percentage of country c's total gross exports, EXGR (c). Calculated for total industry only.

[3] OECD TiVA Database 2021 (Accessed and data extracted on March 2, 2022).

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mobility in India has been slow except in the two-wheeler (E2W) and three-wheeler (E3W) segments (Fig. 1). The four-wheeler (E4W) segment, including passenger vehicles and e-buses, however is yet to observe a rapid wave of penetration.

This study aims to explore the supply side of the EV market. As per industry estimates, there were over 356 EV manufacturers in India in 2022 across various segments of the EV value chains. Most of these producers were functional in the E2W space led by traditional OEMs like Hero Electric and new entrants like Ola Electric and Ampere Vehicles. The E4W market was led by traditional domestic OEMs like Tata Motors and Mahindra Electric with a conspicuous absence of any global OEMs. The incentives were also skewed towards the E2W and E3W market. SMEV reported that the demand incentives approved under Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles in India (FAME) Scheme (Phase-II till October 2022) witnessed the maximum dispersal for E2W while the number of EV models approved were majorly in the E3W segment (Table 1).

Given a country like India that has well established prowess and performance in both manufacturing and global value chain participation in a sector like Automotives, the switch to electric mobility seems to be rather capricious, especially in the four-wheeler segment. While much has already been written about the electric market and EV ecosystem in India, the supply side narrative remains relatively under-explored and understated. This is especially pertinent to the Micro, Small and Medium Enterprises (MSMEs) as they constitute the bulk of the auto ancillaries manufacturing base (more than 80% as per Auto Components Manufacturers Association (ACMA)). This paper intends to address this gap by presenting the incumbent firms' (highlight being the MSMEs) perspectives, based on a firm-level survey, regarding the challenges and opportunities for traditional auto manufacturers in adapting to the electric mobility mission in India. The paper intends to employ the lens of value chain (VC) analysis to better understand the supply side challenges, as it can aid in gaining greater clarity regarding generic and specific issues in each segment of the VC and possible resolutions.

Using PLS-SEM method on data collected from incumbent auto firms in the India, this study aims to explore and understand the major impediments to these firms to adapt to the EV revolution in India. The secondary objective is to analyse which segments of the auto value chain are affected the most by the disruption in the auto value chain in India. The ultimate goal of the paper is to propose certain practical short-term and long-term solutions to these issues as policy recommendations.

The rest of the paper is divided into the following sections – Section 2 outlines a brief literature review on Indian electric mobility and its challenges followed by section 3 which describes the study and the methodology employed. Section 4 presents the PLS-SEM model followed by the results and discussion. Then, in section 5, recommendations for overcoming these supply-side challenges are provided with section 6 concluding the paper with limitations of the study.

Table 1
FAME-II Incentives in 2022 (Source: SMEV Statistics).

Category	Amount	No. of Models Approved
E-2 Wheelers (E2W)	Rs. 2464.27 Cr. approx.	49
E-3 Wheelers (E3W)	Rs. 351.21 Cr. approx.	88
E-4 Wheelers (E4W)	Rs. 114.65 Cr. approx.	23
E-Buses	Rs. 687.93 Cr. approx.	
TOTAL	**Rs 1418.06 (approx.)**	**160**

2. Brief literature review

The shift to EVs in India has been primarily spearheaded by the Government with a combination of production related incentives for auto manufacturers, demand side enticements for the consumers and a regulatory architecture for smooth transition. From the institutional standpoint, there are ample number of policies at the central as well as the state level for promoting buyer conversion, domestic manufacturing and electrification of public transportation. Such policies include the National Electric Mobility Mission Plan (NEMMP), 2012, Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME), Phases I and II and customized state level policies. There is also active Government engagement in information dissemination (e-AMRIT Portal) as well as R&D in partnership with the private sector for several facets of electric vehicles including battery technology and charging infrastructure, according to Government sources.

Extant literature on challenges to electric mobility implementation in India only has been covered in this section, most of which is related to demand-side barriers and infrastructural challenges. Murugan and Marisamynathan (2022) provide a comprehensive review of literature of barriers under several heads that include - EV cost related studies, EV manufacturer related factors, EV technology and vehicle-related factors, infrastructure related factors, road user psychological factors, and EV policy and user awareness related studies based on several economies. Since the context is India for this paper, we have restricted our discussion to papers on the Indian market.

The frequently enumerated challenges to EV adoption from a Indian consumer's perspective include price and performance sensitivity of consumers (as compared to ICE vehicles, EVs are costlier and yet to match the range – speed - efficiency metrics), inadequate charging

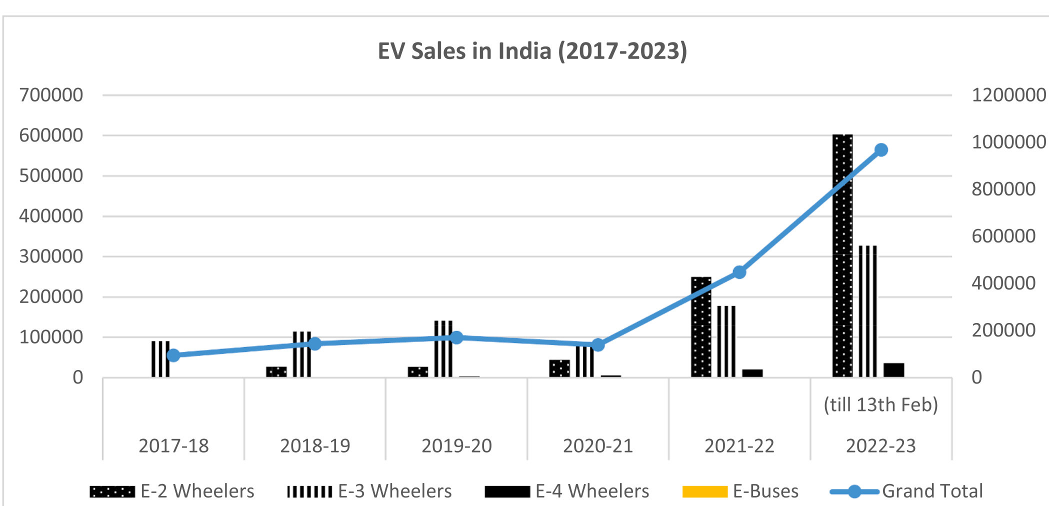


Fig. 1. Sales of Electric Vehicles in India (2015–2022) (Source: SMEV Statistics).

infrastructure (insufficient number of and access to charging stations, long charging times, non-standardized charging equipment) and lack of awareness and experience in EVs (complementary necessity of sensitising the consumers regarding the advantages of EVs for adoption and acceptance).

Balachandra et.al (2010) in their study on diffusion of sustainable energy technologies (SET) in India have highlighted certain specific challenges for India like sceptical customers, lack of adequate incentives, inefficient production and inept regulatory framework for large scale and long-term diffusion of SETs. While the Indian EV industry has evolved since 2015, few key observations of this study are still relevant today in the EV context that impact consumer sensitivities.

Kumar and Chakrabarty (2020) have done a detailed comparative analysis of Total Cost of Ownership (TCO) for EVs in various segments (Table 2). Their analysis shows that though E2W and E3W have witnessed greater mass adoption due to their economic competitiveness as compared to their ICE counterparts, E4W and e-buses will perform better and be more financially viable only with higher daily operation over longer distances. This breakeven analysis explains the slow conversion of public transport into an electric fleet.

Singh et al. (2010) have described all relevant literature related to the EV landscape in India along with outlining the current EV deployment status in India, Government policies as well as the future trends for the market. Their study employs SWOC analysis to identify the challenges and opportunities for EV market in India which include emphasis on promoting research and development (R&D), betterment of infrastructure and acceleration of demand in public transport through government purchases. The various other indicators of the development of EV market in India have been studied under EV penetration levels (Kumar et al., 2015), charging infrastructure (Till et al., 2018; Lokesh and Hui Min, 2017), battery costs and electrification (Levay and Drossinos, 2017; Hagman et al., 2016), EV efficiency (Wager et al., 2014; Strehler et al., 2017) and EV policies (Sierzchula et al., 2014, Figenbaum, 2017; NEMMP, 2020; Virender et al., 2020).

Goel et al. (2021) conduct a barrier analysis for EV sales in India and identify 35 factors based on the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method amongst which familial factors and unclear government policies deter an Indian consumer from buying an EV. Their finding that an average customer is more worried about the lack of maintenance services is corroborated by another study undertaken by Murugan and Marisamynathan in 2022 employing the same method.

Tarei et.al (2021) employ the hybrid two-phased multi-criterion decision making (MCDM) tool to analyse the barriers to EV adoption in India. Their study suggests that performance and range, the total cost of ownership, shortage of charging infrastructure and lack of consumer awareness about EV technology have negatively influenced consumer preference for EVs in India.

Murugan and Marisamynathan (2022) use the Quality Function Deployment (QFD) method integrated with the Analytical Hierarchy Process (AHP) approach to establish similar results for customer hesitance towards EVs that included non-reliability of the vehicle for long trip travels, poor mileage on a full charge, limited-service provider to install charging stations for home-based charging and service centres, and limited spare parts available in local markets. Murugan and Marisamynathan (2022) in another study review the consumer side of EV adoption in India by using the fuzzy DEMATEL method for identification of potential barriers based on discussions with experts and the Relative Importance Index (RII) method for ordering the barriers based on customers' perspectives. They found that the lack of availability of branded EVs, limited maintenance and service facilities and the general want of awareness about EVs have been critical barriers to EV adoption in India according to experts. From the consumers' viewpoint, acquisition cost and performance of EVs have been cited as the biggest barriers for EV adoption. These combined with the concerns regarding maintenance, insurance and battery management have led to low demand.

Jain et.al (2022) explore what affects intention of a consumer to convert to an EV in India using Unified Theory of Acceptance and Use of Technology (UTAUT) in an integrated model. Their analysis reveals that performance expectancy and facilitating conditions have a positive impact on adoption intention, whereas perceived risks affect consumers negatively. They also find that Government support moderates the relationship between perceived risk and adoption intention by reducing the relative impact.

On the supply-side of affairs, EVs have revolutionized the entire auto value proposition, not only by overhauling the existing technology but also by making the automotive value chain more integrated and dependant on Electronics Value Chains and infrastructure. As a result. components manufacturing has gained greater credence and is forcing auto firms (both large and small) to innovate and adapt faster as they are at the frontline of impact. However, there are hardly any studies that delve into the issues that the firms face in adapting to this disruption in India, to the best of the author's knowledge.

This paper, therefore proposes to provide a holistic view on EV adoption in India that includes the firms' perspectives on what impediments they currently experience and perceive for the future in setting up or acclimatizing to EV manufacturing. The paper uses a value chain approach to introduce and examine the firm level challenges in an exploratory study based on a primary survey.

Table 2
Total Cost of Ownership (TCO) for various EVs (Source: Kumar and Chakrabarty, 2020).

Vehicle type	TCO for 10,000 KM (Rs/Km)	TCO for 20,000 KM (Rs/km)	Average Breakeven Daily Distance (in km)
e-2W	2.5	1.31	~14
Petrol 2W	2.17	1.46	
e-3W	1.97*	1.39**	~110
Petrol 3W	2.68*	2.28**	
e-4W (hatchback)	14	7.18	> 55
Petrol 4W (hatchback)	12.69	7.3	
e-4W (sedan)	14.75	8.18	> 164
e-bus (12 m)	94.4#	72.29##	~264

*For e-3W, the distance travelled is 20,000 km; ** For e-3W, the distance travelled is 40,000 km.
#For e-bus, the distance travelled is 45,000 km; ##For e-bus, the distance travelled is 60,000 km.
Breakeven distance is defined as the distance at which the electric vehicle has a lower TCO per km than its fossil fuel variants.

3. Research methodology

A quantitative survey of firms in various segments of the auto value chain was performed as a follow-up of an earlier survey conducted in 2015-16 when NEMMP 2013 was underway in India as a multi-pronged strategy to steer the country towards electric mobility and the subsequent FAME Phase I (2015-18) targeting the development of the domestic manufacturing ecosystem for EVs had been announced (Dash and Chanda, 2022). The sample was drawn based on information provided in the industry directories – Society of Automobile Manufacturers (SIAM) and Automotive Component Manufacturers' Association of India (ACMA). The 2015-16 survey was conducted across all the auto clusters in India with 110 final respondents after the survey was administered, responses were collected and cleaned and incomplete records dropped. This was 27.5% of the total firms approached (400). Measures were taken to make the sample representative across attributes in terms of segment, size, region, type of location, ownership structure and manner of participation in the value chain. The profile of the final respondents has been summarized in Table 3.

The 2021-22 survey was a follow-up survey to the 2015-16 firm-level survey where the same 110 respondents of the previous survey were

Table 3
Profile of the survey respondent firms.

Categories	Final respondents
(A) SEGMENT	
1. OEMs	11
2. Auto Ancillaries	99
(a) Tier – 1 Suppliers	37
(b) Tier – 2 Suppliers	38
(c) Tier – 3 Suppliers	18
(d) Raw Material Suppliers	6
(B) SCALE	
1. Small	12
2. Medium	54
3. Large	44
(C) LOCATION	
North	52
East	12
West	24
South	22
TOTAL	**110**

approached to understand their story so far in adapting to the EV value chain since the announcement in 2015. The typical respondent of the survey was typically at the level of either Vice President (VP)/Director (Corporate Affairs or Business Strategy or Operations) or General Manager (Manufacturing) or Plant Heads who had in-depth knowledge of the firm's current operations and its future outlook.

The survey questionnaire devised after extensive consultations with industry experts and association leaders comprised of both ranking questions where firms were asked to rate factors (on a Likert scale of 1 = "Strongly Disagree" to 5 = "Strongly Agree") that were most likely to impact their decision to adapt to the EV value chain as well as qualitative questions where firms expressed their perceptions regarding future trends. The intent was to keep the questionnaire concise as it was a follow-up survey. The factors were decided and refined based on literature review of published academic papers, newspaper articles and industry reports along with intense deliberations with industry experts (Appendix A). The questionnaire encompassed factors ranging from financial to institutional to regulatory aspects of EV adoption. Since the primary focus of the study is to discover and understand the key aspects of adaptation of the supply side to EV, an exploratory approach was followed. A few sample questions from the survey questionnaire have been provided in Table 4.

This survey was implemented via online and telephonic interviews as well as an online questionnaire to maximize the response rate. It involved tracking key players in each segment of the auto value chain who that had switched to the EV value chain and others who planned to continue in the ICE market. Online and telephonic interviews were more detailed and insightful. In-depth discussions with sector experts belonging to lead firms in respective segments were also held to further understand the current challenges of the firms, especially the MSMEs.

Table 4
Sample questions from the survey questionnaire (Source: Authors' design).

SAMPLE QUESTIONS	
I. RANKING FACTORS:	
1. Rate on a scale of 1-5 if the following factors related to Inputs are important for participation in EV Value Chains.	
a) Raw Materials – Cost	Measures perception of the importance of the input-related factors for EV adaptation
b) Raw Materials – Availability	
c) Raw Materials - Quality	
d) Intermediates - – Cost	
e) Intermediates – Availability	
f) Intermediates - Quality	
2. INDEPTH DISCUSSION:	
1. a) Is your firm committing to EV production? b)If yes, can you give a timeline for the goals set?	
2. What are the top 3 current challenges for your firm in switching to the EV value Chain?	

3.1. Measures

The variables chosen were based on published literature and extensive consultations with experts. For firms, the internal competences related to adoption of any new technology are either capital and cost-related and/or business environment related, especially in the developing countries (Hall and Khan, 2002, World Bank Productivity Project 2022). Hence perception of firms related to these broad factors were measured under inputs-related, financial and technological factors as internal measures, and institutional, trade-related and regulatory factors as external determinants of the switching abilities of traditional auto firms to EV manufacturing lines. A brief summary of the constructs along with the measured items is provided in Appendix A.

3.2. Common method bias

The individual factors were reverse-coded to address method bias. Clear information and instructions to the respondents regarding the academic purpose of the study, assurance of anonymity and voluntary nature of participation was detailed in an attached cover letter to reduce common method bias. The survey covered 35 items which resulted in a large dispersion matrix with the possibility of several pairwise correlations. Hence the large number of variables were simplified using the common dimension reduction technique – Principal Component Analysis (PCA). The Harman's single factor test gave six factors with the highest variance of 28.71%, which validated the presence of multiple explanatory variables.

3.3. Non-response bias

This study used Propensity Score Weighting method to determine if there was any significant non-response bias in the survey. The data was divided into two groups – treatment group which comprised of the firms that had responded "Yes" to EV readiness and the control group comprising of firms that had responded "No" to EV Readiness. Using propensity score weighting, covariates or control variables across treatment and comparison groups in the sample were matched. No significant differences were observed in these covariates related to the firm-level characteristics – age, size, type of location and ownership type – indicating a lack of non-response bias (Table 5).

4. Model

The main objective of this study was to understand the firms' perceptions regarding the challenges and opportunities in adapting to the EV revolution, hence an investigative approach was adopted to analyse the findings. Amongst the various exploratory techniques available, PLS-SEM was chosen since it works best where prior theory is not well established, is better at handling formative measurement models and has advantages when sample sizes are relatively small (Henseler et al., 2016, Hair et al., 2017). Additionally, the PLS-SEM method is not

Table 5
Propensity Score Analysis on Covariates (Source: Author's calculations).

Covariate	PSA (p-value)
Age	0.885
Cluster	0.972
Industry Centre	0.956
Large	0.936
Medium	0.843
Ownership	0.967

concerned with normally distributed data which if of importance since primary surveys typically can entail skewed distribution of data. Our sample size was determined as sufficient for PLS-SEM method as it qualified the "10-times rule" method (Hair et al., 2011; Peng and Lai, 2012) that states that the minimum sample size should be greater than 10 times the maximum number of inner or outer model links pointing at any latent variable in the model (Goodhue et al., 2012), which in case of this study is six. The following tests were conducted to corroborate the robustness of the sample and method.

Since this is an exploratory study, PCA with promax rotation was used on the 32 factors surveyed in order to simplify the dispersion matrix. A total of 6 principal components (now the formative constructs) that had eigenvalues greater than 1 and explained the maximum amount of variation in the sample (cumulative variance of nearly 70%) were derived. Furthermore, the applicability of PCA was validated using the Bartlett test of Sphericity and the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy. Both the results indicated that sampling was adequate (KMO > 0.8) and that the sample had adequate correlations to justify a valid PCA (Bartlett's test p-value = 0.00).

The final model for determining factors affecting EV readiness by automotive firms in India was determined by PLS-SEM method with formative constructs using the SmartPLS 4.0 software.

4.1. The measurement model

The outer model was examined for reliability and validity by assessing the following metrics: indicator reliability, internal consistency reliability, and convergent reliability. The indicator reliability was assessed by calculating the path loadings between the constructs and their indicators. Internal consistency was measured by Cronbach's alpha and composite reliability (CR). Additionally, average variance extracted (AVE) scores were calculated to measure the convergent reliability of each latent construct. The composite reliability (CR) and average variance extracted (AVE) scores for all variables are higher than the recommended thresholds (Table 6).

Convergent validity of the formative constructs reveals if the indicators are redundant. The preferred magnitude of path coefficient is at least 0.6 (Nunnally, 1978, Chin, 1998). None of the reflective constructs in the study are found to be less than 0.6 except for two (but they were retained due to relatively higher magnitude > 0.5) supporting high indicator reliability (Table 7).

The Variance Inflation Factor (VIF) used to measure collinearity should ideally have value of lower than 5 to avoid any potential collinearity problem (Hair et al., 2011). None of the constructs had a VIF score greater than 5 (Table 8).

For the inner model, the discriminant validity of the constructs using both the Fornell-Larcker criterion and heterotrait-monotrait ratios (HTMTs) was assessed. As per the Fornell-Larcker criterion, the square roots of the AVE value should be higher than pairwise correlations for individual latent constructs in order to establish discriminant validity (Henseler et al., 2016). Table 9 shows that the 6 latent constructs fulfil this criterion corroborating their validity.

To further establish more robustness in the discriminant validity assessment, the HTMT ratios were also calculated (Table 10). All values are less than the upper limit of 1 indicating that discriminant validity is acceptable (Henseler et al., 2016).

Table 6
Reliability and Validity.

	Cronbach Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
Financial	0.692	0.808	0.552
Inputs	0.906	0.946	0.672
Institutional	0.796	0.794	0.2
Regulatory	0.944	0.946	0.755
Technology	0.698	0.822	0.5
Trade	0.923	0.962	0.751

4.2. The structural model

The total effects of the estimated model are described in Table 11 below. The individual path coefficients of the structural model determined by the PLS algorithm signify the influence of the formative constructs (explanatory variables) on the endogenous latent variable (explained variable) and can be interpreted as standardized beta coefficients of a regression. The coefficient of determination for the final model has a R^2 of 0.45, which might suggest moderate to low explanatory power of the model but the results are verifiably acceptable for firm-level surveys that usually have small sample sizes and might be affected by factors beyond the scope of a particular study (Goodhue et al., 2012; Felipe et al., 2019; Alam et al., 2020; Szász et al., 2021). The effect size (f^2) that is used along with R^2 to determine the effect of an explanatory construct had values above the small impact threshold (>0.02) (Verma and Goodale, 1995). The overall model fit with an SRMR value of 0.043 is good as it is well below the commonly accepted threshold of 0.08 (Henseler et al., 2016).

The most significant factors that the firms deemed highly important for enabling them to adapt to the Electric mobility mission are *Financial, Regulatory* and *Technological*. According to the firms, the shift to the new value chain entails both immediate and long-term financial planning in terms of capital costs and borrowings since they have to strike a balance between continuing their current offerings and preparing for the future with a revised or adapted or new product line. This also accentuates the role that investment incentives and subsidies from the Government can play.

The existing laws and policies (both at the Centre and States-level) are viewed as encouraging by the auto firms in helping them with the transition. Amongst the significant regulations/policies, the Manufacturing Policy (NNEMP and FAME), Emission Norms as well as the Import Policies have a positive impact on EV readiness for firms. Additionally, FDI policy, environmental laws and trading policies are perceived to have a positive impact on preparing the firms for the shift.

The third most significant factor deemed important by the firms is technology. Since EV technology is revamping the entire auto value chain, firms have the perception that the cost, availability and quality of technology will be important factors for making the transition to EV production. In addition, restrictions of technology transfer by policy or partner firms and the constant requirement of technology upgradation are also key elements of adapting to the EV manufacturing.

The factors that apparently have insignificant impact are Inputs-related, Trade-related and Institutional. While this might be partly explained by the fact that at the time of conducting the survey, the cognizance of the role to be played by inputs (raw materials and intermediates) and the dependence on trade for the same might not have been expressively present, these factors do affect EV readiness of auto firms in India.

5. Results and discussion – the firms' perspective

The broad findings of the full model (Fig. 2) have been discussed below in further detail, by enriching them with the qualitative answers received from the firms.

Financial factors: Huge capital investments for adaptation, innovation and survival are compulsory across all segments of the EV value chain. The cost of doing business for all auto firms has escalated due to the imperative of high-end technology and has been exacerbated due to financial constraints of capital and credit (access, quantum, and quality) affecting the domestic firms' capability to develop mass EV production capacity. Firms have deemed tax rates and interest rates as highly important as well. For instance, the inverted GST structure in the industry where raw materials for various segments are taxed at a higher 18–28%, batteries and other parts at 18%, tyres at 28% while the

Table 7
Factor Loadings.

	Financial	Inputs	Institutional	Regulatory	Technology	Trade
Capital Costs	0.800					
Interest Rates	0.836					
Investment Incentives	0.899					
Subsidies	0.790					
Raw Material Availability		0.866				
Raw Material Cost		0.807				
Raw Material Quality		0.820				
Intermediates Availability		0.838				
Intermediates Cost		0.775				
Intermediates Quality		0.812				
Competition in VC			0.522			
Risks of VC			0.570			
Standards of VC			0.608			
Governance of VC			0.770			
Emission Norms				0.946		
Environment Laws				0.761		
Export Policy				0.778		
FDI Policy				0.839		
Import Policy Partner				0.836		
Import Policy				0.949		
NNEMP_FAME				0.951		
Technology Availability					0.904	
Technology Cost					0.905	
Technology Quality					0.904	
Technology Restrictions					0.144	
Technology Upgradation					0.619	
Documentation						0.961
International Transport						0.957
Standards of Partner						0.747
Tariffs on Imports						0.852
Trade Agreements						0.794

Table 8
Component Correlation Matrix and VIF for Principal Components.

Component	1	2	3	4	5	6	VIF
1. Inputs related	1.000						1.24
2. Institutional	−0.454	1.000					1.185
3. Trade related	0.354	0.082	1.000				1.15
4. Technological	−0.061	0.439	0.173	1.000			1.347
5. Regulatory	0.004	0.203	0.276	0.191	1.000		1.129
6. Financial	−0.119	0.337	0.135	0.213	0.194	1.000	1.131

Table 9
Discriminant validity assessment based on the Fornell-Larcker criterion.

	Financial	Inputs	Institutional	Regulatory	Technology	Trade
Financial	**0.743**					
Inputs	0.500	**0.820**				
Institutional	−0.026	−0.108	**0.445**			
Regulatory	0.012	0.202	−0.038	**0.869**		
Technology	0.001	−0.065	0.110	−0.028	**0.694**	
Trade	−0.178	−0.024	0.189	0.072	−0.049	**0.867**

Table 10
HTMT ratios estimated for each pair of constructs.

	Financial	Inputs	Institutional	Regulatory	Technology	Trade
Financial						
Inputs	0.564					
Institutional	0.400	0.637				
Regulatory	0.105	0.202	0.140			
Technology	0.297	0.170	0.366	0.062		
Trade	0.262	0.111	0.180	0.265	0.108	

finished EVs are taxed at 5% have been a major source of financial concern, especially for the small and medium enterprises. Charging infrastructure including battery-swapping services are also charged at 18%. This has been a major cause of concern for the entire EV industry as it is affecting both the profitability of businesses and affordability of end products.

Table 11
Total Effects of various factors on EV Adoption Readiness by firms (Source: Based on the survey).

Paths	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	t statistics	P values
Financial -> EV_Readiness	0.317	0.303	0.043	7.403	**0.000**
Inputs -> EV_Readiness	−0.055	−0.047	0.055	0.989	0.323
Institutional -> EV_Readiness	0.036	0.063	0.072	0.501	0.617
Regulatory -> EV_Readiness	0.096	0.112	0.036	2.633	**0.009**
Technology -> EV_Readiness	0.085	0.074	0.046	1.816	**0.064**
Trade -> EV_Readiness	−0.028	−0.023	0.029	0.942	0.346

The nature of the auto industry is such that modification of the value chain dictates high capital costs and advance planning and strategizing. Commitments for adjusting manufacturing lines and product offerings demand huge investments coupled with long gestation times for projects to yield results. While most Indian OEMs have committed to implementing electric mobility (either hybrid models or full EVs), the results will take a few years to show. EVs entail high market entry costs which are a major challenge for small firms without the support, guidance and business of a lead firm or OEM. On the other hand, the incumbents are facing the dual challenge of adapting to the new technology while maintaining their time-earned edge over new entrants.

Regulatory factors: India's EV revolution has been primarily Government driven and started in 2010 when the Ministry of New and Renewable Energy earmarked Rs 95 crores as financial incentives for EV manufacturers. The National Electric Mobility Mission Plan (NEMMP) 2013 was intended as a multi-pronged strategy to steer the country electric mobility with demand side incentives for consumers to switch to EVs and supply side incentives worth Rs 1000 crore for production along with emphasis on developing R&D and allied infrastructure. The subsequent Faster Adoption and Manufacturing of Electric Vehicles (FAME, Phase I (2015–18) and Phase II (2019–22)) targeted the development of the domestic manufacturing ecosystem for EVs. The latest scheme announced by the Central Government is the Production Linked Incentive (PLI) Scheme which aims to further incentivize battery and auto ancillary manufacturers to ramp up production with an outlay of Rs 26,058 crores over five years. PLI offers incentives based on the annual increase in output or sales with the intent of promoting economies of scale, ensuring efficiency and competency through adoption of cutting-edge technology.

Although well intended, the conditions of eligibility under the FAME-II and PLI schemes have been criticised as non-inclusive, especially by the MSMEs. As per the FAME-II guidelines, only those companies that locally sourced 50 per cent of the components used in the EV manufacturing (40% for EV buses) are included. As a result, most products are automatically excluded and the ones that do meet these stringent criteria do not get sufficient subsidies to close the price gap with ICE counterparts.

Similarly, the eligibility criteria under PLI mentions group revenue (including global streams) of Rs 1000 crore for OEMs and Rs 500 crore for ancillaries. Additionally, there should be total investments in fixed assets of Rs 3,000 crore and Rs 150 crores for OEMs and the components respectively along with commitment for minimum local investments ranging between Rs 250–2,000 crores over the next five years. So, this again disqualifies a large number of MSMEs and most start-ups that have been forerunners of the EV revolution in the country. While Government subsidies are what the EV industry requires at present, such stringent criterion might need to be revisited for domestic capacity building. The state government incentives have been better received.

The regulatory factors have set the ecosystem for EV manufacturing in India and are perceived as the biggest enablers of the transition for firms across all segments of the EV value chain.

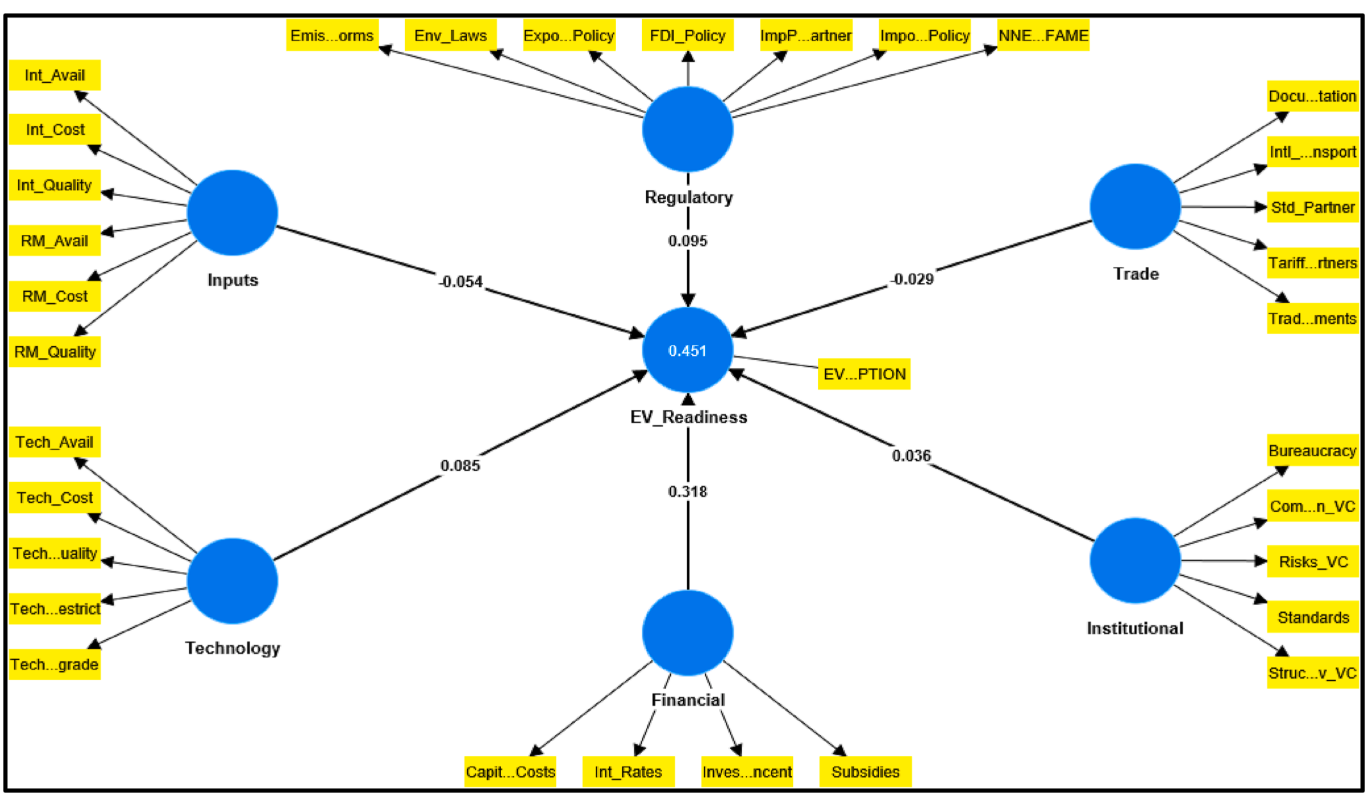


Fig. 2. Full model depicting factors of EV Adoption readiness by Automotive Firms in India.

Technology-related Factors: One of the biggest deciding factors that firms feel they have encountered in developing EV-related abilities is adequate technological support. This includes not only Research and Development (R&D) for EV specific knowledge but also access to latest processes and manufacturing knowhow including best global industry practices, and technology transfer restrictions from non-allied partners. Segments like battery, integrated drivetrain and recycling that are completely new to the auto value chain demand heavy and aggressive investment in R&D for not only finding novel solutions for performance (in terms of size, durability, sustainability) but also need to factor in costs constraints and mass production capabilities to reap the benefits of economies of scale.

For instance, for the battery technology, a range of options including lithium-ion, lead acid, sodium/magnesium-ion and supercapacitors are being explored worldwide for better efficiency and compact size. But research abilities that can effectively use locally available raw materials for batteries are yet to develop in India, which is still majorly dealing with lithium ion batteries for EV through imports. Focussing on the battery value chain will have payoffs through reduced dependence on other countries and sustainable domestic value chains.

The focus of technology is not only on novel solutions but also on enabling commercial production for catering to the growing demand and solving complexity of design and integration. The cost-quality-quantity trade-off are a growing concern for manufacturers across segments. Significant outlays are being concentrated on commercialization of electrical components, integrated circuitry, light-weight material fabrication, and battery technology. Furthermore, combining several power electronic components in a single design is being pursued in order to reduce the cost and weight of EVs while improving the quality of experience and safety.

Technological disruption in the auto value chains is also related to change in the type of raw materials used for various parts of an EV. For instance, since the EV is powered by a rechargeable battery, to conserve energy and ensure better on-road performance, the body of the EV is switching to lighter materials like Aluminium, Advanced High-Strength Steel (AHSS) and Composites (fibreglass, carbon fibre, and thermoplastics).

Other major technological concerns cited by the firms include constant standards compliance by domestic and international partners, continuous technology upgradation, long design to revenue cycles and ability to diversify products. MSMEs particularly are finding it tough to meet these expectations.

Input-related factors: The availability, quality and cost of raw materials and intermediates for manufacturers in every section of the value chain have been a major concern for all firms, large or small. At present, all segments are rather dependent on imports for inputs, which come with associated problems of costs, logistics-related challenges, and uncertainties of external economies. For instance, manufacturing of lithium-ion (Li-ion) battery cells requires critical raw materials such as lithium, cobalt and nickel, that India neither produces nor has capacity for processing. Similarly, due to limited technical expertise and experience, the incidence of rejection of domestic components has also gone up, sometimes up to 25% as per industry sources, compromising on dependability of domestic offerings and greater reliance on imported components. Table 12 summarizes the major EV components that are imported in India with the top sourcing country being China.

The missing domestic electronics ecosystem is majorly affecting firms across the segments and making them more dependent on imports. According to Ministry of Electronics and IT (Meity), the domestic value addition in electronics in 2021 was 18% and is expected to touch 25% by 2022. However, electronics, especially power electronics, which form a substantial share of EVs require specialized technology and manufacturing proficiency of their own. For instance, electronic chips are a highly demanded component but dictate the toughest technical exercise along with huge capital investments, robust power and water infrastructure, specialized services and skills network that India currently lacks. Such factors preclude MSMEs in EVVCs, and only large firms with adequate resources can meet the challenges.

Table 12
Top EV imports for India (in USD Millions) (Source: Ministry of Trade and Commerce).

Top EV components	2018–19	2019–20	2020–21
Other Motor with output $<$ 37.5Watts	180.7	115	115.5
Other Motor with output $>$ 37.5 Watts	171.69	151.75	133.32
Transistor other than photosensitive ones	239.9	320.4	311.2
Lithium ion	1225.9	1246.2	1192
Monolithic Digital ICs	4723	5150	5063
Parts of electronic integrated circuits and micro assemblies	480.52	986.28	810.5
Switching Diodes	229.2	217.2	214.8
Parts of electric motors (DC)	46.02	41.73	37.95
Parts of electric motors other than DC	26.17	22.95	19.7
Parts of other rotating electric plants	422.07	442.87	295.92
Electric inverters	167.4	180.74	214.7
Battery chargers	68.63	50.41	90.74
Electrical vehicles of heading 8709	222.99	177.11	148.21

Trade-related factors: Technological challenges have led to excessive dependence on trade (mostly imports) for current EV manufacturing in India, thereby exposing more Indian firms to trade and trade related barriers. Large firms that have greater GVC participation in traditional auto value chain have the edge not only due to their size but also due to their international network. Even though significant amount of innovations is by newer firms, GVC participation has empowered the incumbents with basic trading knowledge, lowered search costs in markets where they have previous network connections and pre-knowledge of how to be export-competitive.

According to most firms, trade-centric activities like search cost for reliable partners, creating and maintaining contracts, customs documentation and procedures, long turnaround times at the ports are assuming greater significance in this backdrop as they add to the cost of operations, especially for MSMEs. Smaller firms that were not previously direct participants of any GVC are hence finding it particularly punishing for making forays into the EV market.

High import tariffs and localization decrees have also made trade even more difficult and/or exclusionary, especially for MSMEs. Import tariffs on crucial components (motors, controllers, chargers) range between 5 and 15% while vehicles (completely knocked down to completely built units) attract tariffs between 25 and 40%. Even with direct participation in auto GVCs, MSMEs are realising growing dependence on lead firms for finding dependable suppliers, both domestically and internationally.

Additionally, logistics-related shocks like unavailability of shipping containers, interrupted and delayed shipments, rising freight charges against a backdrop of limited capacity, rising fuel costs and pandemic-marred labour have only added to higher imports costs. Geo-political ramifications have further fuelled uncertainties in trade. A global value network that showcases flexibility and resilience to aggregate shocks can prove invaluable for trade. Trade agreements can be effective in such conditions where trading partners can be all-weather friends and firms have an assurance regarding the maintenance of supply chains even in the event of unexpected crises.

Institutional factors: Institutional factors that are specifically related to the organization and governance of the auto value chain have an insignificant impact on EV readiness of Indian firms. Conventionally, the auto value chain is often fragmented at the lower value-added segments (Tier – 2 and Tier -1) while being more concentrated at the higher value-added segments (OEMs). The governance pattern is often central (Gereffi et al., 2005). According to the firms, these structural and governance designs if extended to EV value chain will not have any substantial impact on their adaptation. Rather, some firms strongly feel that strategic collaborations with lead firms in various segments of the value chain will in fact help them overcome other constraints like technological barriers and trade-related impediments. Additionally, the conspicuous absence of major international OEMs, especially in the four-wheeler segment, is causing concern amongst their MSME supplier network as they believe they could have relied on lead firms for hand-holding them through this disruption.

6. Value chain perspective

The EV value chain is significantly different from the traditional auto value chain as EVs are distinctive from traditional automotives mechanically and electronically. They are simplified in terms of the total number of components, the number of moving parts, as well as critical sub-systems like transmission and exhaust systems. For instance, most EVs are equipped with single-speed transmissions; hence do not require super or turbochargers to provide extra oxygen flow to the engine or exhaust systems to remove waste gases. The rechargeable battery is the heart of an EV and replaces the entire fuel tank-engine-carburettor setup. Electric Batteries also have their own distinctive value chain. Hence EVs have heralded in newer manufacturing processes that are highly innovation-centric and will render several segments of the traditional auto value chain obsolete.

Key differences in the various segments of the traditional versus EV manufacturing value chain are outlined in below (Table 13). The type and level of impact on firms in each segment can be categorized into four broad categories as "*No Change*" for those segments that do not require extensive customization for EVs, "*Obsolete*" for the segments that will not be a part of the EVs and "*Adapt*" and/or "*Innovate*" for categories that range from minor adaptation for firms with small changes to their current product offerings (like adjusting the type of raw material or trivial variations in the design) to major revamps for firms that need to reconstruct major sections of or entire production lines and/or design processes.

Based on extensive discussions with the firms, Fig. 3 maps out the entire Electric Vehicle Value Chain (EVVC) highlighting the current performance of India in various segments. This enriched the quantitative findings of the study that highlighted the major challenges to converting to EV production. This is a novel attempt to map out the entire EV VC by incorporating both manufacturing and services segments where value is added and recognizing which segments will most likely be affected the most by the disruption.

The perception of the firms in Tier-1 and Tier-2 segments of the auto value chain regarding their future prospects in the EV value chain as India embraces the EV revolution were also gathered. The snapshot of some of the responses have been reported below in Table 14.

7. Implications and conclusion

This paper provides an overview of the major challenges and opportunities in adapting to electric mobility mission in India from the supply-side angle, which none of the previous studies have covered. This exploratory study is the first of its kind to take into consideration the perception of the firms, especially the MSMEs who form the majority of the auto components manufacturers' base in India, for enumerating the production-related challenges to manufacturing EVs. The use of PLS-SEM modelling gives a reliable methodology to present the firm-level survey data in a quantitative manner. The value chain approach, also novel to the study, makes the analysis more detailed and provides a comprehensive picture of the production related challenges involved for electric mobility adoption.

The study finds that incumbent auto and auto-component producers in India perceive financial and technology-related factors as most disadvantageous in making the switch to the EV value chain while regulatory factors including the various central and state level schemes have been deemed as facilitative. Financial factors like commitments for capital investments, cost of borrowing, lack of adequate subsidies and inadequate financial incentives across various segments of value addition have been flagged as major deterrents, especially by the smaller firms which typically do not have ready access to capital or credit. On the technological front, access to EV-related technology and costs involved in constant upgradation have been perceived as handicaps by the Indian auto firms.

Government schemes that offer financial aid and ease access to better infrastructure have been considered as useful by the firms, even if the basic qualification criteria currently restrict the benefits to mostly the larger players. Apart from these factors, value chain facets like structure and governance within the VC as well as higher integration with foreign markets due to greater dependence on imports for inputs (raw materials and intermediates) and technology have been deemed as major factors affecting Indian auto firms for rapid EV adoption.

For successful adaptation, innovation and survival across all

Table 13
Differences between Traditional Automotive Systems and Electric Vehicle Systems in various manufacturing segments (Source: Adapted from Ardebili, Pecht & Zhang 2009).

Category	NIC CODE 2008	Traditional Automotive Systems	Electric Vehicle Systems	Impact
Energy storage	29209	Fuel Tank	Rechargeable Batteries (E.g. Lithium ion batteries, Nickel Manganese Cobalt batteries)	Innovate
Energy conversion	29104, 29304	EFI (electronic fuel injection), ECU (engine control unit), Starter, Alternator, Battery	Electric Motor, AC-DC Inverter and Converter, Power electronics for on-board charger (Power Delivery Module), Charging Stations	Adapt and Innovate (Obsolete)
Energy transfer	28140	Multi-speed gear box: TCU (transmission control unit), KCS (knock control system), cruise control, cooling fans	Fixed ratio Gearbox, Single speed transmission unit, Reduction Drive	Adapt
Chassis	29103	Chassis, Active four-wheel steering, active control suspension	Skateboard chassis design (chassis fitted with battery and electronic motors) Active four-wheel steering, active control suspension, Composites	Adapt and Innovate
Safety	29301; 29302; 28120	ABS (anti-lock brake system), TRC (traction control system), VSC (vehicle stability control), Airbag system Preset steering wheel position	Regenerative Braking System, VSC (vehicle stability control), Airbag system Preset steering wheel position	Adapt (Obsolete)
Body	29201	Mild Steel, Aluminium	Aluminium, Advanced High-Strength Steel (AHSS), Composites (fibreglass, carbon fibre, and thermoplastics)	Innovate
Comfort & convenience	29303; 27400; 22191; 22111	Climate control, power seat, power windows, door lock control, mirror controls, tyres	Climate control, power seat, power windows, door lock control, mirror controls, tyres	No Change
Displays & audio	27900	Radio (AM, FM, satellite), CD player, TV and DVD player, cellular phone, navigation system, instrument cluster	Radio (AM, FM, satellite), CD player, TV and DVD player, cellular phone, navigation system, instrument cluster	No Change
Assembly	29101; 29102	Assembly of final vehicles	Assembly of final vehicles	Adapt
Recovery	38300	Not Applicable	Precious metals from Battery	Innovate

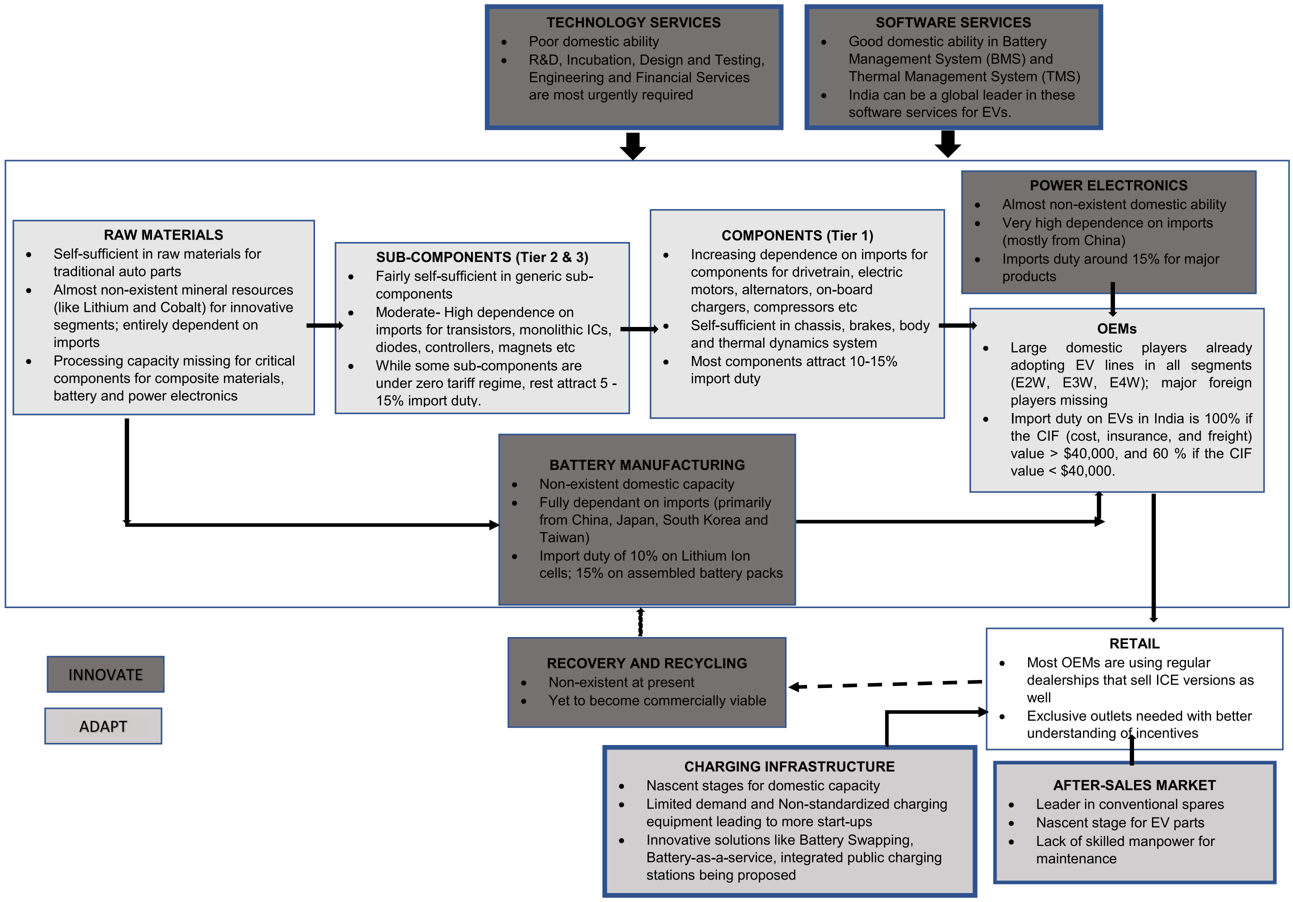


Fig. 3. India's performance in each segment of the Electric Vehicle Value Chain (Source: Author's compilation).

Table 14
Perception of Auto Firms in India regarding the future outlook (Source: Survey).

EV segment	Approx contribution to total cost of vehicle	Current capabilities	Future outlook (for 2030)
Chassis and Body	10–15	Good	Extremely good
Electric Motor and Alternator	10–12	Very Poor	Poor
Power Electronics	8–10	Very Poor	Poor
Battery	35–40	Very Poor	Poor
Software for Management Systems	10–15	Very Good	Extremely Good
Final Assembly (OEMs)	10–15	Good	Extremely Good

segments of the EV value chain, association with major players that possess innovation advantages, whether resourceful incumbents or inventive new entrants, is the key. Thus, for greater domestication of the EV value chain, the OEMs and large firms across auto segments in India have to pave the path. MSMEs need to focus on the quality of their network to remain relevant and potentially alleviate major challenges.

7.1. Policy implications

At the industry level, the focus needs to shift to ground-breaking innovations as incremental innovations will no longer suffice. While building R&D capabilities might seem an uphill task at present, it will be inevitable in the future and the returns to such investment will be clearly visible soon. Manufacturing crucial components at economies of scale is an imperative and can progress by identifying the best value-added parts to manufacture in line with the present capabilities. With EVs presenting an entirely new VC, value can be captured by firms that are agile enough to innovate and adapt. While foreign counterparts are deemed to have the first mover advantage for possessing cutting-edge technology and perfecting the mass manufacturing processes, domestic incumbents can also garner value by harnessing the prevailing technologies that match their existing capabilities the best. Even if small firms believe it will require massive efforts to even attempt joining an EV GVC without adequate knowledge transfer and pecuniary support, the OEMs and lead firms have an opportunity of developing the national ecosystem with curated supplier base by lending the desired backing.

India needs to focus not only on the automotive manufacturers, but also on developing allied electronics and charging infrastructure manufacturing base. Greater participating in GVCs can be a first step as this usually increases technical knowhow with these chains act as conduits of knowledge transfer across geographies between partners. Centralized R&D facilities for the entire industry with contributions from members and knowledge sharing at structured prices can also help develop scale through aggregation. Finally, harmonization of design and technologies across models and across producers could help minimize product and ecosystem development expenses.

India's auto manufacturing is also looking to benefit from co-location advantages of auto and core-IT proficiency in integrating Internet of Things (IoT) and Artificial Intelligence (AI) in EVs. The budding Hosur Cluster along the borders of Karnataka and Tamil Nadu is one such example of the evolving landscape. Localised components manufacturing through greater integration across the auto clusters in the four corners of the country could help build robust value chains that could warrant flow of high-end technology, innovation and investments across the entire buyer–supplier network. Diversity in capabilities of large and small firms could in fact be a promising resource base for

OEMs.

7.2. Managerial implications

Managerial decision making needs to focus on the technological front as a priority. Tactical collaborations with domestic or foreign partners can help solve the issues of technical dependence in the short run, till local capabilities can be built over the long run. While MSMEs will probably not be able to undertake R&D on their own, OEMs can provide technical and financial assistance for developing such capabilities in order to build a robust supplier base; so MSMEs need to focus on building a robust network.

Two vital strategic fields for EV value chain are R&D and recycling and material recovery. Battery chemistry for size, efficiency and performance are urgent targets of major innovations. Value chain related constraints can be further alleviated by novel propositions in value addition and business models like leasing and swapping. For instance, the partnership between Hero Electric and Gogoro of Taiwan that aims to utilize the widely acclaimed Gogoro swapping technology for its next generation offerings could be a template for such effective alliances between OEMs and charging infrastructure providers.

7.3. Limitations of the study and future scope

The study has certain limitations – (a) the study was able to collect responses from a limited number of firms. Though care was taken to ensure that the sample was representative, a greater number of responses would have made the study truly representative; (b) the number of factors to explain the challenges and opportunities could have been more extensive but were limited due to the relatively small sample size. Future studies can collect data from a greater number of firms and add more effectuating factors. Furthermore, the analysis of these factors can be extended to policy level in order to understand the impact of central and state policies on EV value chain adoption in a more minute manner.

Though the success story of India's electric mobility mission has so far remained confined to the two-wheeler (E2W) and three-wheeler (E3W) segments, the headwinds indicate the future potential of the auto industry in India. Growing EV adoption entails certain adaptableness on the behalf of suppliers and manufacturers in order to improve the commercial viability of EVs, boost customer confidence with performance and variety offerings and fabricate innovative solutions for the future. The value chain approach employed in this paper helps identify the key challenges faced by auto firms in India in various segments to adapt to the EV value chain and contributes to better preparedness measures, especially the small and medium firms, for the supply-side of EVs in the future.

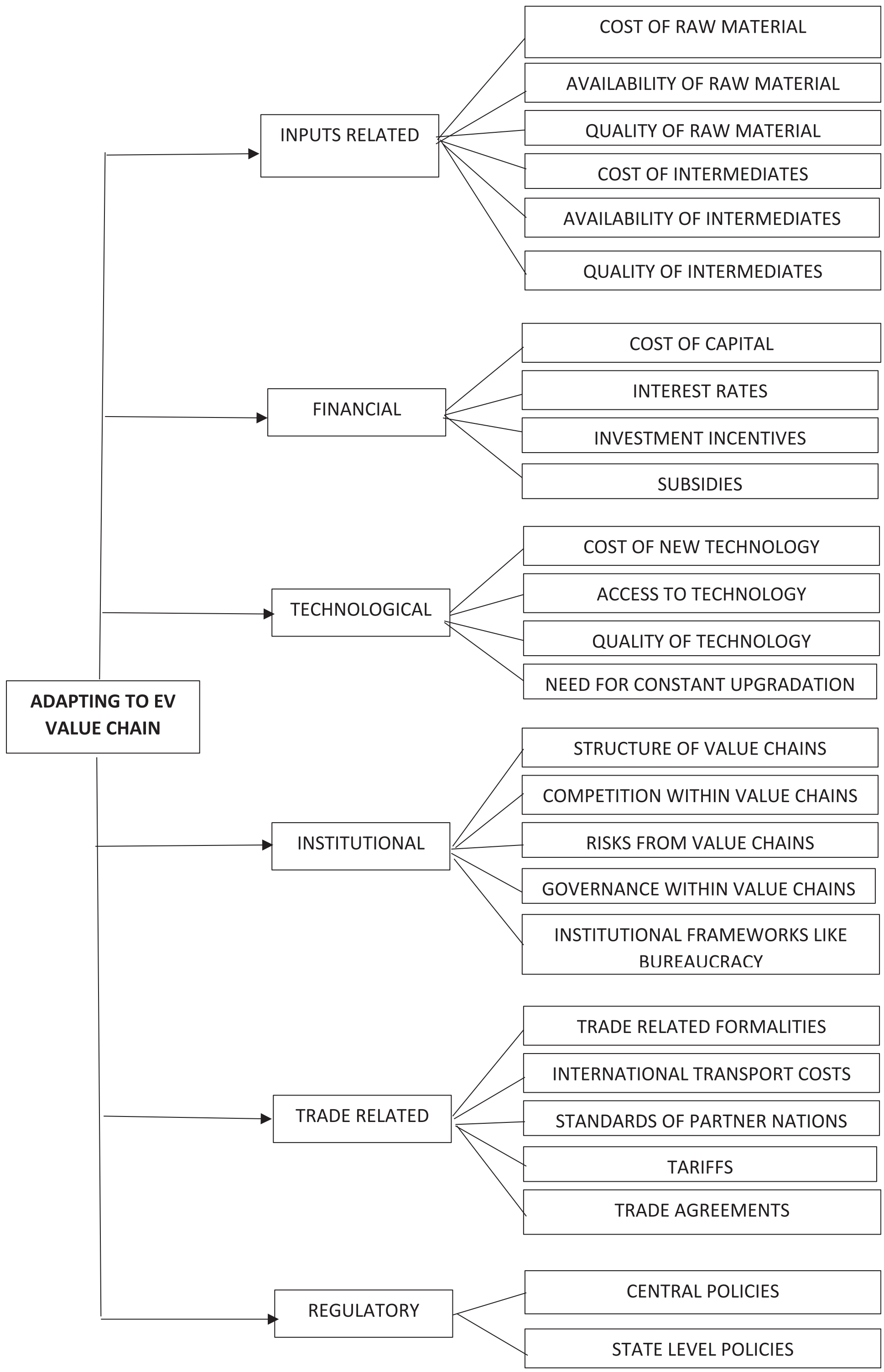
CRediT authorship contribution statement

Ankita Dash: Conceptualization, Methodology, Software, Visualization, Investigation, Data curation, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A



References

Alam, M.N., Masroor, I., Nabi, M.N.U., 2020. Does entrepreneurs' risk perception influence firm's rapidity in foreign market entry through moderation of entrepreneurial decision-making approach? Rev. Int. Business Strategy 30 (2), 225–243.

Balachandra, P., Kristle Nathan, H., Reddy, B.S., 2010. Commercialization of sustainable energy technologies. Renew. Energy 35 (8), 1842–1851. https://doi.org/10.1016/j.renene.2009.12.020.

Chin, W.W., 1998. The partial least squares approach to structural equation modelling. In: Marcoulides, G.A. (Ed.), Modern Methods for Business Research. Lawrence Erlbaum, Mahwah, NJ, pp. 295–358.

Dash, A., Chanda, R., 2022. Anatomizing India's presence in automotive global value chains. Foreign Trade Rev. 57 (4), 429–451. https://doi.org/10.1177/00157325211039909.

Dyerson, R., Pilkington, A., 2005. Gales of creative destruction and the opportunistic incumbent: the case of electric vehicles in California. Technol. Anal. Strategic Manage. 17, 391–408. https://doi.org/10.1080/09537320500357160.

Felipe, C.M., Leidner, D., Roldán, J., Leal-Rodríguez, A., 2019. Impact of IS capabilities on firm performance: the roles of organizational agility and industry technology intensity. Decis. Sci. 51 (3), 575–619. https://doi.org/10.1111/deci.12379.

Figenbaum, E., 2017. Perspectives on Norway's supercharged electric vehicle policy. Environ. Innov. Societal Transitions 25, 14–34. https://doi.org/10.1016/j.eist.2016.11.002.

Gereffi, G., Humphrey, J., Sturgeon, T., 2005. The governance of global value chains. Rev. Int. Political Econ. 12 (1), 78–104. https://doi.org/10.1080/09692290500049805.

Goel, P., Sharma, N., Mathiyazhagan, K., Vimal, K.E.K., 2021. Government is trying but consumers are not buying: a barrier analysis for electric vehicle sales in India. Sustainable Production and Consumption 28, 71–90. https://doi.org/10.1016/j.spc.2021.03.029.

Goodhue, D., Lewis, W., Thompson, R., 2012. Does PLS have advantages for small sample size or non-normal data? MIS Q. 36 (3), 981–1001. https://doi.org/10.2307/41703490.

Hagman, J., Ritźen, S., Stier, J.J., Susilo, Y., 2016. Total cost of ownership and its potential implications for battery electric vehicle diffusion. Res. Transp. Bus. Manage. 18, 11–17. https://doi.org/10.1016/j.rtbm.2016.01.003.

Hair, J., Hult, G., Ringle, C., Sarstedt, M., 2011. A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM). SAGE, Washington DC.

Hair Jr, J.F., Sarstedt, M., Ringle, C.M., Gudergan, S.P., 2017. Advanced issues in partial least squares structural equation modeling. SAGE publications.

Hall, B.H. and Khan, B. (2002) Adoption of New Technology. New Economy Handbook. Berkeley University, Berkeley, 1-38. doi: 10.3386/w973.

Henseler, J., Hubona, G., Ray, P., 2016. Using PLS path modelling in new technology research: updated guidelines. Ind. Manag. Data Syst. 116, 2–20. https://doi.org/10.1108/IMDS-09-2015-0382.

Jain, N.K., Bhaskar, K., Jain, S., 2022. What drives adoption intention of electric vehicles in India? An integrated UTAUT model with environmental concerns, perceived risk and government support. Res. Transp. Bus. Manag. 42, 1–9. https://doi.org/10.1016/j.rtbm.2021.100730.

Kumar, A.G., Anmol, M., Akhil, V.S., 2015. A strategy to enhance electric vehicle penetration level in India. Procedia Technol. 21, 552–559. https://doi.org/10.1016/j.protcy.2015.10.052.

Kumar, P., Chakrabarty, S., 2020. Total cost of ownership analysis of the impact of vehicle usage on the economic viability of electric vehicles in India. Transp. Res. Rec. 2674, 563–572. https://doi.org/10.1177/0361198120947089.

Lee, K., Malerba, F., 2017. Catch-up cycles and changes in industrial leadership: windows of opportunity and responses of firms and countries in the evolution of sectoral systems. Research Policy 46, 338–351. https://doi.org/10.1016/j.respol.2016.09.006.

Levay, P., Drossinos, Y., 2017. The effect of fiscal incentives on market penetration of electric vehicles: A pairwise comparison of total cost of ownership. Energy Policy 105. https://doi.org/10.1016/j.enpol.2017.02.054.

Lokesh, B.T., Hui Min, J.T., 2017. A framework for electric vehicle (EV) charging in Singapore. Energy Procedia 143, 15–20. https://doi.org/10.1016/j.egypro.2017.12.641.

Marra, M., Pannell, D., Abadi Ghadim, A., 2003. The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: Where are we on the learning curve? Agric. Systems 75, 215–234. https://doi.org/10.1016/S0308-521X(02)00066-5.

Murugan, M., Marisamynathan, S., 2022. Elucidating the Indian customers requirements for electric vehicle adoption: An integrated analytical hierarchy process – quality function deployment approach. Case Studies on Transport Policy 10 (2), 1045–1057. https://doi.org/10.1016/j.cstp.2022.03.017.

National Electric Mobility Mission Plan (NEMMP) 2020. Government of India. https://heavyindustries.gov.in/writereaddata/Content/NEMMP2020.pdf.

Nunnally, J.C., 1978. Psychometric Theory, 2nd ed. McGraw-Hill, New York.

Parente, S., Prescott, E., 1994. Barriers to technology adoption and development. J. Political Econ. 102 (2), 298–321. https://doi.org/10.1086/2619332.

Peng, D., Lai, F., 2012. Using partial least squares in operations management research: a practical guideline and summary of past research. J. Operations Manage. 30, 467–480. https://doi.org/10.1016/j.jom.2012.06.002.

Sierzchula, W., Bakker, S., Maat, K., Wee, B., 2014. The influence of financial incentives and other socio-economic factors on electric vehicle adoption. Energy Policy 68, 183–194. https://doi.org/10.1016/j.enpol.2014.01.043.

Society of Manufacturers of Electric Vehicles (SMEV). https://www.smev.in.

Strehler, M., Merting, S., Schwan, C., 2017. Energy-efficient shortest routes for electric and hybrid vehicles. Transp. Res. Part B: Methodological 103, 111–135. https://doi.org/10.1016/j.trb.2017.03.007.

Szász, L., Csíki, O., Béla-Gergely, R., 2021. Sustainability management in the global automotive industry: a theoretical model and survey study. Int. J. Prod. Econ. 235, 108085 https://doi.org/10.1016/j.ijpe.2021.108085.

Tarei, P.K., Chand, P., Gupta, H., 2021. Barriers to the adoption of electric vehicles: evidence from India. J. Clean. Prod. 291, 125–147. https://doi.org/10.1016/j.jclepro.2021.125847.

Till, G., Thomas, S.S., Zhenhong, L., Patrick, P., Changzheng, L., Jens, B., 2018. What drives the market for plug-in electric vehicles? – A review of international PEV market diffusion models. Renewable and Sustainable Energy Reviews 93, 158–164. https://doi.org/10.1016/j.rser.2018.03.055.

United Nations Framework Convention on Climate Change (2015). The Paris Agreement 2015 (FCCC/CP/2015/10). (https://unfccc.int/process/conferences/pastconferences/paris-climate-change-conference-november-2015/paris-agreement).

Verma, R., Goodale, J.C., 1995. Statistical power in operations management research. J. Oper. Manag. 13 (2), 139–152. https://doi.org/10.1016/0272-6963(95)00020-S.

Virender, S., Vedant, S., Vaibhav, S., 2020. A review and simple meta-analysis of factors influencing adoption of electric vehicles. Transp. Res. Part D: Transp. Environ. 86 https://doi.org/10.1016/j.trd.2020.102436.

Wager, G., Bräunl, T., Whale, J., McHenry, M.P., 2014. Enhanced EV and ICE vehicle energy efficiency through drive cycle synchronisation of deferred auxiliary loads. Int. J. Electric Hybrid Vehicles 6 (3), 179–194. https://doi.org/10.1504/IJEHV.2014.065725.

World Bank Productivity Project Report (2022). World Bank. https://www.worldbank.org/en/topic/competitiveness/brief/the-world-bank-productivity-project.