d·i·e

50 Years | 1964 – 2014

Deutsches Institut für Entwicklungspolitik

German Development Institute

Discussion Paper 15/2014

Electromobility in India

Attempts at Leadership by Businesses in a Scant Policy Space

Ankur Chaudhary

Joint project with:

IDS Institute of Development Studies

Tsinghua University
School of Public Policy and Management

Indian Institute of Technology Delhi

Electromobility in India

Attempts at leadership by businesses in a scant policy space

Ankur Chaudhary

Bonn 2014

Discussion Paper / Deutsches Institut für Entwicklungspolitik
ISSN 1860-0441

Die deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.d-nb.de abrufbar.

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data is available at http://dnb.d-nb.de.

ISBN 978-3-88985-634-0

Ankur Chaudhary obtained his Bachelor in Technology in Engineering Physics from IIT Delhi in 2009 and received the Director's Silver Medal and the Mudit Sharma Memorial Gold Medal for academic performance. Following a brief stint in technology-focused consulting, he joined Indian Institute of Technology as a researcher on the innovation and development issues, with a particular emphasis on energy, environment and technology.

E-mail: ankurch.cstaff@iitd.ac.in

© Deutsches Institut für Entwicklungspolitik gGmbH
Tulpenfeld 6, 53113 Bonn
☎ +49 (0)228 94927-0
🖷 +49 (0)228 94927-130
E-Mail: die@die-gdi.de
www.die-gdi.de

Abstract

Electric vehicles are increasingly seen as a critical component of global climate change mitigation efforts. This view, coupled with the co-benefits of energy security, industrialization and job creation, among other things drives the response of various stakeholders. In a national framework – with linked factor and demand conditions – such responses are leading to the emergence of various national electromobility trajectories. Within these, the Indian case is unique in terms of its emerging automobile sector, energy security constraints and a weak innovation system in general. An interplay of policy, business strategy, technology competence and market forces is shaping the present nature as well as the future direction of the Indian trajectory. This paper presents three case studies in the Indian electromobility sector and uses the lessons learned from these cases to identify and analyse the key trends, both technological as well as organizational, that are shaping and emerging in this trajectory. The paper highlights attempts by Indian firms, made in spite of the absence of a strong policy push, at integrating electromobility in their business strategies and the resulting innovation system attributes.

Acknowledgements

The author would like to thank the interviewees from TVS, TATA Motors, KPIT Cummins, Mahindra REVA, Hero Electric, ACMA, SIAM, BEE, IIT Delhi, TIFAC, NATRiP, NSDC, MNRE and CSE for their valuable case study and sector insights reported in this paper.

New Delhi, March 2014 Ankur Chaudhary

Preface

Mitigating climate change by reducing carbon emissions is one of the biggest and most complex issues the world has ever faced. Technological innovation plays a major role in taking on this challenge. Old and new industrial powers alike are increasingly reforming their policy frameworks to encourage low carbon innovation, and investments are following.

Evolutionary economics has clearly demonstrated how initial choices of technologies and institutional arrangements preclude certain options at later stages; hence, situations evolve in an incremental and cumulative way, resulting in context-specific technological pathways. Such path dependency implies that technologies and institutions do not progressively converge toward a unique best practice, as neoclassical equilibrium models might suggest. The historical and social embeddedness of such evolutionary processes instead results in a variety of very different technologies and institutions across countries.

The starting assumption of our research was that low carbon technologies depend on politically negotiated objectives and policies to a particularly high degree, mainly due to the failure of markets to reflect environmental costs. The way national governments and industries deal with the low carbon challenge varies greatly depending on levels of environmental ambition, technological preferences (such as different attitudes towards nuclear energy, shale gas, carbon capture & storage), the ways markets are regulated, and the importance attached to expected co-benefits (such as exploiting green jobs or energy security). Consequently, low carbon technologies are more likely to evolve along diverging pathways than other technologies whose development is more market-driven.

To test this assumption we conducted the international research project "Technological trajectories for low carbon innovation in China, Europe and India". The project explored whether, to what extent and why technological pathways differ across countries. Case studies were conducted in two technological fields, electromobility and wind power technologies, in China, India and leading European countries. Whether a diversity of pathways emerges or a small number of designs becomes globally dominant has important implications. From an environmental perspective, diversity may help to mobilize a wide range of talents and resources and deliver more context-specific solutions. Convergence, on the other hand, might help to exploit economies of scale and thereby bring about bigger and faster reductions in the cost of new technologies. From an economic perspective, diversity may provide niches for many firms, whereas a globally dominant design is likely to favour concentration in a small number of global firms – which may or may not be the established ones. Comparing European incumbents with Asian newcomers is particularly interesting, because China and India might well become the gamechangers – responsible for most of the increase of CO_2 emissions but also leading investors in green technology. In addition, the project explored lessons for international technology cooperation, emphasizing ways to navigate the trade-offs between global objectives to mitigate climate change effects and national interests to enhance competitiveness and create green jobs locally.

The project was carried out between 2011 and 2014 as a joint endeavour of four institutions: the German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE), Institute of Development Studies (IDS) Brighton, Indian Institute of Technology (IIT) Delhi and the School of Public Policy at Tsinghua University, with additional collaborators from the Universities of Aalborg, London and Frankfurt. The project was truly collaborative, to the extent that international teams jointly conducted interviews in China, India and Europe which helped to build common understanding.

Eight reports have been published in, or are currently being finalised for, the DIE Discussion Paper series:

1. Schamp, Eike W. (2014): The formation of a new technological trajectory of electric propulsion in the French automobile industry.

2. Chaudhary, Ankur (2014, forthcoming): Electromobility in India. Attempts at leadership by businesses in a scant policy space.

3. Altenburg, Tilman (2014, forthcoming): From combustion engines to electric vehicles: Implications for technological trajectories. Case study Germany.

4. CHEN Ling, Doris FISCHER, SHEN Qunhong and YANG Wenhui (2014, forthcoming): Electric vehicles in China – Bridging political and market logics.

5. Lema, Rasmus, Johan Nordensvärd, Frauke Urban and Wilfried Lütkenhorst (2014, forthcoming): Innovation paths in wind power: Insights from Denmark and Germany.

6. DAI, Yixin, Yuan ZHOU, Di XIA, Mengyu DING, Lan XUE (2014, forthcoming): Innovation paths in the Chinese wind power industry.

7. Narain, Ankita, Ankur Chaudhary and Chetan Krishna (2014, forthcoming): The wind power industry in India.

8. Bhasin, Shikha (2014, forthcoming): Enhancing international technology cooperation for climate change mitigation. Lessons from an electromobility case study.

On the basis of these case studies, the team is currently working on a series of cross-country comparative analyses to be published in academic journals.

The research team is very grateful for generous funding and a very supportive attitude by the Swedish Riksbankens Jubileumsfond under a joint call with Volkswagen Foundation and Compagnia de San Paolo.

Bonn, April 2014 Tilman Altenburg

Contents

Boxes

Abbreviations

ACMA	Automotive Component Manufacturers Association (of India)
AFSTP	Alternate Fuel for Surface Transportation Program
ARAI	Automotive Research Association of India
BEE	Bureau of Energy Efficiency
BEV	Battery electric vehicle
BMS	Battery management system
CAGR	Compounded annual growth rate
CNG	Compressed natural gas
CSE	Center for Science and Environment
EGR	Exhaust gas recirculation
EV	Electric vehicle
FY	Financial year
GDP	Gross domestic product
GHG	Greenhouse gases
GPS	Global positioning system
HEV	Hybrid electric vehicle
IBEF	Indian Brand Equity Foundation
IC	Internal combustion
ICE	Internal combustion engine
IEA	International Energy Agency
IIT	Indian Institute of Technology
INR	Indian rupee
IP	Intellectual property
IPO	Initial public offering
IT	Information technology
JV	Joint venture
JWG	Joint Working Group
KWh	Kilowatt-hour
MNRE	Ministry for New and Renewable Energy
NATCOM	National Communication (Project)
NATRiP	National Automotive Testing and R&D Infrastructure Project
NCEM	National Council for Electric Mobility
NEMMP	National Electric Mobility Mission Plan
NGO	Non-governmental organization
NSDC	National Skill Development Council
OEM	Original equipment manufacturers
OICA	Organisation Internationale des Constructeurs d'Automobiles
PHEV	Plugin hybrid electric vehicle
R&D	Research and development
REEV	Range-extended electric vehicle
SIAM	Society of Indian Automotive Manufacturers
SUV	Sports utility vehicle
TIFAC	Technology Information, Forecasting and Assessment Council
UNIDO	United Nations Industrial Development Organization
USD	United States dollar

1 Introduction

Electric vehicles (EVs), one could argue, have replaced wind turbines and solar farms as the archetypical climate change mitigation technology, capturing the fancy of the media as well as policymakers worldwide. And not without good reasons. While the fascination of the popular press with the mobile technology for the common man is quite understandable, the scale of energy consumption and the greenhouse gas (GHG) emissions from the transport sector rightly justify the concerns of policymakers. According to International Energy Agency (IEA) estimates, globally 26% of primary energy is consumed for transport purposes, and 23% GHG emissions are energy-related (IEA 2009). Moreover, with the global car fleet expected to triple over the next four decades, working to reduce transport sector GHG emissions appears to a be a good strategic bet from a climate change mitigation perspective (ibid.). Of course, there are several competing technologies (such as improved internal combustion engines [ICEs], fuel cells, air powered cars etc.) that offer the promise of a cleaner mobility; however, at present electromobility[1] is the principal thrust area in policy and strategy discussions (see Table 1) in firms, national governments as well as international bodies.

Table 1: Announced EV deployment targets for major automobile market countries

Country	Target (Year)	Target Attributes
Australia	20% (2020)[1]	% of production numbers
China	540 000 (2015)[2]	Stock numbers
	20%–30% (2030)[3]	% of market share
France	2 000,000 (2020)[4]	Stock numbers
Germany	1 000,000 (2020)[5]	Stock numbers
Japan	20% (2020)[6]	% of market share
UK	1 200,000 (2020)[7]	Stock numbers
US	1 000,000 (2015)[8]	Stock numbers for PHEV
India	N.A.	–

Sources: [1] Mitsubishi Australia; [2] Pike Research; [3] McKinsey & Company; [4,5,6] Electric Vehicle Initiative (EVI); [7] Department of Transport, UK; [8] Presidential Announcement

The allure of electromobility is even greater for developing countries. Almost 80% of the growth in the global car fleet up to 2050 is projected to occur in rapidly developing countries such as India and China, possibly resulting in crippling fossil fuel dependence for these countries. Furthermore, reduced tailpipe emissions from electric cars promise to yield significant health and ecological benefits in the urban areas. Another consideration, one that is

1 This paper defines electromobility in vehicles as including any vehicle that uses an electric motor for propulsion (and not just regeneration) purposes, while excluding fuel cell driven vehicles. As a result, mild-hybrids, full-hybrids, plug-in hybrids as well as pure electric vehicles are included in this definition. See section 2 for more details. Further, in this document batter-electric vehicles (BEVs) imply pure battery driven vehicles with no ICE drivetrain; plug-in hybrid electric vehicles (PHEVs) imply hybrid vehicles with an external recharging capability while the term hybrid electric vehicles (HEV) is used to designate vehicles with both the electric as well as ICE drivetrain (details in section 2).

not as crucial for some other climate change mitigation technologies, is the opportunity of industrialization around electric vehicle manufacturing with associated economic development and job creation benefits: a very strong motivation for developing country policymakers.

In India, the transport sector is the second largest contributor to energy related GHG emissions, with a share of over 7.5% of national emissions in 2007, up from 6.4% in 1994 (NATCOM 2010). Between 1951 and 2004, the vehicle population in the country grew at a compound annual growth rate (CAGR) of close to 11% (Singh 2006). At the same time, the lack of organized urban transport in several large cities has encouraged this move towards increased personal mobility, with the share of public transport in cities with population sizes over 4 million declining from 69% to 38% between 1994 to 2007 (Singh 2006).

Despite this recent surge in vehicle numbers in the country, the motorization levels remain much lower than those in the developed countries. For example, in 2009, car ownership in India was about 18 per thousand, much below developed country numbers (which are generally over 400).[2] This low penetration represents a high growth potential for car numbers in the country, with all the underlying growth determinants i.e. urbanization, income levels and middle class population following an upward trajectory. However, this growth has not been without the associated vexations.

A majority of the transportation fuel used in India is imported, with the gap between oil consumption and domestic production worsening each year. With the 2011–2012 oil import bill at USD 140 billion or almost 10% of the GDP, this represents a huge energy security challenge for India (Hindustan Times 2012, June 13). Further, the increase in vehicle numbers has impacted the urban air quality, particularly in metropolitan areas such as Delhi and Mumbai. Incidentally, as far as GHG emissions per car go, the Indian car fleet ranks among the best in the world (with an almost 39 mpg fleet average), a manifestation not of technological prowess but of the lower car weights in India.[3]

With these trends and tribulations in mind, it would seem that EVs, with their promise of emissions mitigation, fossil fuel dependency alleviation and possible industrialization would present compelling deployment cases in the Indian transportation sector. Indeed, Indian policymakers have shown interest in this emerging technology, having dabbled in incentives for promoting electromobility. At the same time, the promise of a paradigm shift in the traditional automotive sector presents a great opportunity (as well as challenge) for the emerging car makers in India, both in domestic and global markets, leading to a private sector interest in electromobility. A combination of these factors has, over the past few years, led to increased EV-focussed activity in the Indian automobile innovation system.

At present, within the global automobile sector, the holy grail for EVs seems to be automobiles that offer the performance characteristics of current ICE vehicles: quick "recharge" time and significant driving range, all at a reasonable price (see IEA 2013). However, given the nascent stage of associated technologies, firms and policymakers are exploring possible pathways forward while trying to hedge short-term technology bets. Globally, in the case of electromobility, we see a departure from the traditional internal combustion engine production ecosystem: component makers (including the battery makers)

2 World Bank estimates: http://data.worldbank.org/indicator/IS.VEH.NVEH.P3

3 Read more at http://www.beeindia.in/schemes/documents/s&l/BEE%20Consultation%20Paper-21Oct2011.pdf

and non-firm actors such as utilities, NGOs or regulatory bodies, etc., are becoming more important. This is hardly surprising since the innovation around electromobility is multi-variegated and complex.

Against this backdrop, as one looks at the nascent and still evolving Indian EV technology trajectory, a complex interplay of policy, business strategy, technology competence and market forces is emerging, shaping both the present nature as well as the evolution of this trajectory. This paper aims at identifying and analysing the key trends, both technological as well as organizational, that are shaping or emerging within this trajectory.

In terms of analysis methodology, since a firm technology trajectory is so far absent, we look at innovation cases to better understand the emerging technology trajectory and the overall electromobility landscape in India. While there are a number of electromobility projects, products and prototypes in India, we explore cases that provide particularly useful insights into the character and evolution of the trajectory. For this purpose we have set forth a selection criterion (see section 5 for details) that ensures a selection of cases which represent not just significant innovation within the sector, but also reflect commercial commitments and country specific causal relationships. Based on these criteria, we have selected three cases within the Indian electromobility story that taken together present a reasonably complete picture of the Indian EV sector both in terms of the player types as well as technologies involved.

Two sets of interviews have contributed to the paper and its findings. The first set of interviews, undertaken during March–April 2012, was used to provide insights into the evolution, present state and key trends in the Indian electromobility trajectory. These interviews were also useful in shortlisting interesting innovation cases in the sector that we could analyse deeper in the second round of interviews. As a result, the first round of three interviews was held with key informants from IIT Delhi, the National Skill Development Council (NSDC) (the informant was also the ex-Director General of the Society of Indian Automotive Manufacturers [SIAM]) and the Ministry of New and Renewable Resources (MNRE).

A second set of interviews was aimed at understanding, analysing and drawing insights from cases that were selected by applying our case selection criteria to the cases shortlisted during the first round of interviews. These interviews were conducted during December 2012 to March 2013 and included interviews with: TATA Motors (3), TVS (3), KPIT Cummins (3), Mahindra REVA (1), Hero Electric (1), the Automotive Component Manufacturers Association (1), SIAM (2), the Bureau of Energy Efficiency (1), TIFAC (1), NATRIP (1) and CSE (1). The number in parenthesis indicates the number of interviewees within each organization. All the interviews were semi-structured, with questions aimed at understanding the process, drivers, implications and nature of innovation in each case. While Interviews in TVS, KPIT Cummins and Mahindra REVA involved firms within which the cases materialized, the other interviews were used to triangulate and confirm the assertions and trends as stated in other interviews.

To supplement the interviews, additional policy, market, players and trend-related information was derived from desk research involving scholarly articles, government data and announcements as well as grey literature (newspaper articles, magazines, company websites etc.).

This paper consists of six sections. To aid a more informed discussion later, sections 2 and 3 present a brief overview of, respectively, the global state of electromobility and the Indian automobile industry. Following this, section 4 details the emerging electromobility innovation path in India. A detailed discussion on the selected innovation cases in section 5 puts this discussion in perspective while highlighting the factors driving or thwarting the trajectory's growth. The paper concludes in section 6 with a discussion on the insights we can draw from the various cases towards understanding India's unfolding electromobility trajectory.

In essence, the paper starts with the historical, structural and technological character of the sector; identifies key learning through a close analysis of important cases within the sector; delves into the role of various actors, institutions and market conditions in shaping the overall trajectory; and concludes with a characterization of the technological trajectory of the sector, hopefully structured enough to warrant a cross-country and cross-sectorial comparison with country studies on China (Fischer et al. 2014), France (Schamp 2014) and Germany (Altenburg 2014) which have been conducted in parallel.

2 Electromobility: what, why and how

2.1 Characteristics and trends of electromobility technology

To gain a better understanding of the policy, business and innovation issues around EVs, it is helpful to have some background of electromobility technologies, their deployment benefits as well as the various challenges towards deployment. This section starts with a brief background of the technology involved in EVs, highlighting the major technology sub-systems as well as the various competing product configurations. The following discussion assumes no prior technical knowledge on the part of the reader and attempts to explain the technology in an easy to understand manner, to the extent possible.

EVs, for the purposes of discussion in this paper, are vehicles powered (either partially or fully) by an electric motor as against an ICE.[4] An EV uses energy stored in its batteries, which are recharged by electricity from household/utility-provisioned power points or through a generator powered by an on-board ICE. At the moment, given the emerging technology, ranges of products exist with varying drivetrain mechanisms, recharging mechanisms as well as battery chemistries.

In general parlance, EVs that use purely electric power (recharged by external electricity sources) with no ICE on-board are referred to as pure battery EVs (BEVs) while vehicles that use electric power to increase fuel efficiency by pairing an ICE with one or more electric motors are referred to as hybrid EVs (HEVs). In hybrids, the petrol engine is typically the more powerful of the two sources (though this is not necessarily the case), providing most of the power during acceleration, with the electric motor usually providing some electric-only operation besides capturing energy as the car slows, in a process called regenerative braking, by temporarily shifting into generator mode. Another class of vehicles, one that has a longer electric-only range and only uses a small ICE for charging batteries in case of longer drives has also emerged under the label of range extended electric vehicles (REEV).

In terms of technology complexity, EVs arguably represent some of the most complex technological products in widespread use (except perhaps consumer electronics). The major vehicle sub-systems in the form of drivetrains, batteries, motors, control and management

4 Fuel cell powered vehicles are however not discussed in this paper.

systems, chassis etc. are all complex systems in their own right. The present portfolio of available technologies and associated products ranges from simple systems that capture the easiest fuel efficiency gains through simple technology interventions to complex engineering masterpieces that are run completely on electrons.

Figure 1 below seeks to provide a broad characterization of the different types of EVs so as to enable a more informed discussion later in the paper. Please note that although micro-hybrids (vehicles employing just stop-start mechanisms) are not included in our discussion of electro mobility here; they are included in the table for the sake of completeness as far as the industry phrasing goes.

From an end-user's perspective[5], the primary arguments in favour of EVs include reduced tailpipe emissions (zero in the case of pure EVs) and a higher fuel efficiency (in the case of hybrids), leading to reduced dependency on oil and lower running costs when compared to vehicles powered by petrol.

From a global warming and urban pollution viewpoint, the tailpipe emissions of EVs are generally[6] reduced (for hybrids) or completely absent (pure EVs). This makes EVs quite attractive as means of mitigating the climate change impacts of CO_2 emissions and the health impacts of SO_x, NO_x and particulate matter emissions from the transportation sector. However, for countries that rely heavily on coal for power generation, the electricity used by EVs has linked emissions at the power plants. As a result, an exact comparison of the 'emissions relief' due to EV deployment in a country is contingent upon the emission profiles of its power generation sector and transportation fleet. For example, in India, where a majority of the power generation base is coal based, significant emissions are linked with each unit of electricity consumed by the electric vehicles. On the other hand, for a country like France, where nuclear power comprises over three-fourths of the power generation base, the electricity expended by EVs has a much lower carbon footprint. Thus, with a move towards renewable systems of power generation, EVs are expected to become more environment-friendly as the electricity gets cleaner. Yet for countries like India (and China) where coal is projected to comprise a significant fraction of the power generation mix at least until 2050, the emissions reduction potential of EVs remains limited (World Energy Outlook 2010).

For cost considerations, electricity is generally cheaper than petrol, thus leading to lower running costs of a transportation system reliant on EVs. That said, high battery costs (over \$500/KWh in 2011, with a pure EV like Nissan Leaf requiring about 24 KWh of battery capacity) coupled with the need to replace batteries after six to eight years means that the life cycle cost of EV ownership is still higher than that of the conventional vehicles powered by petrol. On the brighter side, with advancements in battery technologies and a scale effect kicking in, the cost of batteries, according to a recent McKinsey report, could plunge to \$200/KWh by 2020, thus substantially increasing the cost competitiveness of EVs vis-á-vis conventional vehicles (Hensley / Newman / Rogers 2012)

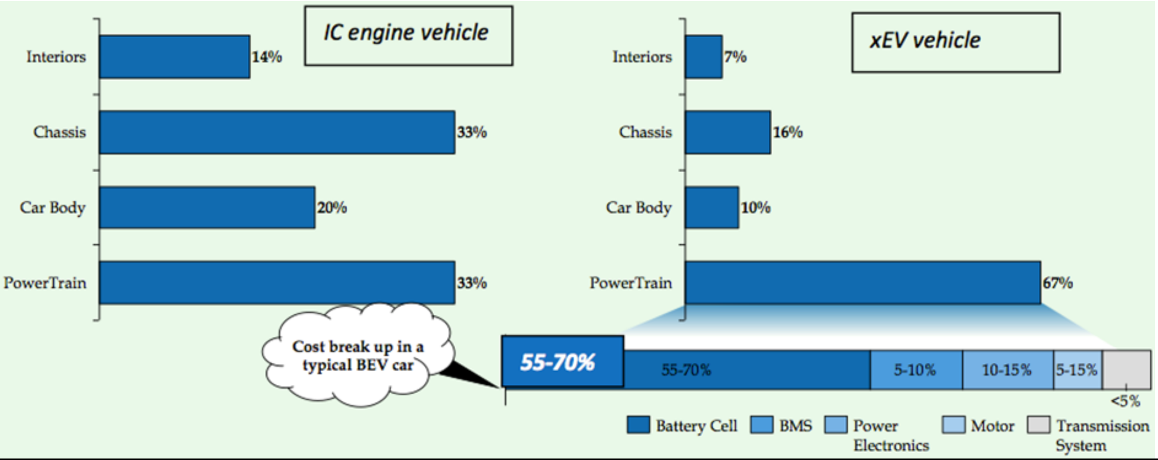
At the risk of digressing, it is instructive to look at Figure 1 that illustrates the difference between the cost of various sub-systems in ICEs and BEVs. As against traditional ICE vehicles, where chassis and drivetrain contribute almost 33% to the vehicle cost, in four-

5 Other factors, with the specific business or policymakers' perspective, are discussed in the following sections.

6 Depending on the source of electricity that powers the vehicle.

wheeler BEVs the powertrain costs are much higher, contributing almost 67% (range 55% – 70%) of the total vehicle cost. In the powertrain the battery cell and power electronics dominate, with the contribution of the battery cells depending on the size of the battery pack (see distribution bar at the bottom right of Figure 1).

Figure 1: Comparative assessment of the relative cost of technology sub-components within ICEs, hybrids and pure battery EV (BEVs)



Please note that the overall cost of hybrids is generally higher than ICEs

Source: NEMMP 2012

Despite the conditional advantages mentioned earlier, the shift to EVs is fraught with other considerable challenges besides those of higher production costs. Most pure EVs can go only a limited distance between charges, considerably limiting their driving range. Even though a public recharging infrastructure could solve this issue, the four to eight hours recharge time and the significant capital costs of developing such an infrastructure presents a major limitation to EV deployment. In the case of hybrids, while the range issue is resolved (with alternate power from the petrol engine), the presence of two power mechanisms still leads to increased vehicle cost and technology complexity.

Further, from an infrastructural perspective, the impact of this additional electricity withdrawal on the power grid is still not clear, especially for power starved developing countries like India where demand often outstrips the supply of electricity. Innovative solutions to these challenges such as battery swapping stations (to exchange depleted batteries with charged ones) or vehicle-to-grid technologies, while deployed within small pilot projects, are still too expensive for a wide-scale roll-out.

It is clear that for most end users, EVs do not make a compelling case against the IC vehicles – at least not yet. In recognition to this free-market deployment challenge[7] to this emerging technology, policy makers world-wide have initiated support programmes to further EV development and deployment. Of course, with varying policy motivations and industrial capabilities across various geographies, the design of these policies looks different in different countries. Section 2.2 below presents a brief overview of such efforts across the globe and the policy motivations and industry dynamics that are shaping these efforts.

7 The challenge consists not just of the technological barriers but also of current energy subsidies on fossil fuels, inadequate infrastructure and locked-in consumer psychology.

Table 2: Taxonomy of electric / hybrid vehicles

	Micro hybrids	Mild Hybrids	Full Hybrids			Pure EVs	
		Parallel Hybrids	Series Hybrids (Range Extenders)	Power Split	Plug-in Hybrids	Low Speed	High Speed
Technologies	Combustion Engine	Combustion Engine	Combustion Engine	Power Split	External battery charging	External battery charging	External battery charging
	Stop-Start	Regenerative braking	Regenerative braking	Combustion Engine	*Power Split*	Regenerative braking	Regenerative braking
		Engine Assist	Engine Assist	Regenerative braking	Combustion Engine	Stop-Start	Stop-Start
		Stop-Start	Stop-Start	Engine Assist	Regenerative braking	Generator	Generator
		Electric Motor	Generator	Stop-Start	Engine Assist	Electric Motor	Electric Motor
		Supercapacitors	Electric Motor	Generator	Stop-Start	*Supercapacitors*	*Supercapacitors*
			Supercapacitors	Electric Motor	Generator		
				Supercapacitors	Electric Motor		
					Supercapacitors		
Battery only mode:	No	No	Yes	Yes	Yes	Yes	Yes
ICE only mode:	Yes	Yes	No	Yes	Yes	No	No
Battery	Lead Acid (Small)	Li-ion (small)	Li-ion (Large)	Li-ion (Large)	Li-ion (Large)	Lead Acid (Large)	Li-ion (Large)
Technology maturity	Mature	Evolving	Evolving	Mature (Prius)	Evolving	Mature	Evolving
Examples:	Several	Honda (Integrated Motor Assist System)	Suzuki Swift RE	Toyota Prius	Chevrolet Volt		Nissan Leaf

The battery chemistry is indicative of vehicle model used to illustrate category and not representative of all vehicles in the category.

Source: Company websites

2.2 Global efforts, policy motives and industry dynamics

Efforts to kick-start electric mobility are underway in several countries across the globe. These efforts, in the US, the EU, China, Israel, Australia and elsewhere, have been focused on research, development as well as deployment of EVs in their respective transportation systems (IEA 2013). As such, these efforts span initiatives by, among others, national governments, firms, provincial or local governing bodies, and research focussed institutions.

Broadly, the pathways that different countries have adopted towards electromobility have been influenced by two major factors. Firstly, the primary strategic motives of the policymakers (as detailed later in this section) have a bearing on the chosen development and deployment path for electric vehicles in the respective countries. Of course, no single motive is present in any country that influences policy making; however, the importance attached to the various motivating factors influences the final shape of the policy. Secondly, countries and firms need to act and plan in recognition of their present standing vis-à-vis the development of electric vehicles. Where are they now? What do they plan to accomplish in the future? How do they plan to do it? How does this plan fit into the shifting global landscape? Answers to these questions on financial, technological and political dimensions shape the response of stakeholders within the electromobility paradigm.

While achieving climate change mitigation and controlling urban pollution have been among the major stated policy motivations for countries to promote electric mobility, other considerations such as strategic thinking around energy security and industrialization have also played an important role. For example, for the US, the EU, China and India, a heavy dependence on imported petroleum poses a serious energy security challenge that could be countered by developing a transportation system based on electricity (which in their case is primarily generated through abundant domestic coal reserves).

Further, given the large scale on which EVs may soon need to be deployed globally to address the climate change mitigation imperative and the present industrial stature of ICE manufacturing that they aim to replace, it is strategically imperative for countries to develop manufacturing prowess and competitive advantages in the emerging sector that could emerge as a keystone for their industrial base.

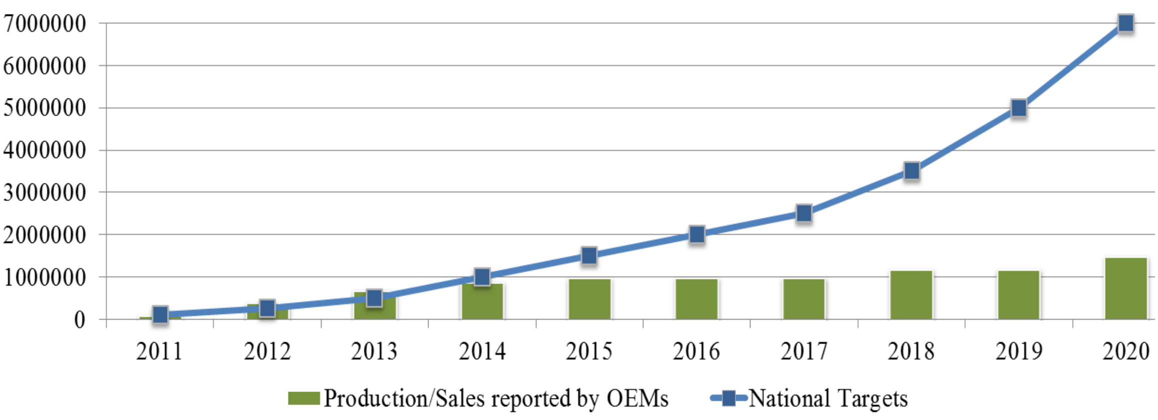
Even though the automobile sector represents one of the most globalized and tiered industries in the world, we are still far from a perfect technologically porous world, with the result that firms still Figure specific technology competencies. Further, the strong domestic economy contribution of developed country automobile firms and dreams of national champions in the auto sector in developing countries leads policymakers to favour domestic technologies. Countries make policies that favour their domestic players and present realistic technology targets for them. For instance, it is interesting to look at the focus of German and French EV policies in juxtaposition with the EV product portfolio of the domestic original equipment manufacturers (OEMs) in these countries. With domestic firms in France (Renault and Citroen) having EVs in market, the French policy is geared towards increased deployment through demand side incentives. On the other hand, in the absence of any major EV products available from the German OEMs, the policy focus in Germany has been on strengthening the technology competence in EV technologies through R&D investments. A detailed discussion of the political economy of electromobility across EU, China and India is presented in Altenburg / Bhasin / Fischer (2012).

From an industrial organization perspective, the globally growing impetus of electromobility is gradually leading to a shuffle-up in the traditional automobile manufacturing value chain. For example, component suppliers work very closely with OEMs in conventional car and related product development and a clear understanding of value chain upgrading can be attained fairly simply. However, new components required to drive the electromobility trajectory (powertrain components, batteries, controllers etc.) have thrown open an opportunity for varying suppliers to build competence without OEM support. Demand for electric motors, batteries, battery management systems and control systems represents a chance for traditional and non-traditional industry actors to invest, build and compete within the still emerging EV supply chain. These efforts are to a great extent influenced or supported by government agencies looking to promote research and development (R&D) in this sector, particularly in the US, Japan and the EU.

Not only is there a new space for growth for traditional component manufacturers, but also ample opportunities for completely new entrants and entrepreneurs. For instance, chemical companies like Dow, BASF and Samsung are investing in newer battery technologies; electric motor manufacturers are developing better motors for specific vehicle usage patterns; and completely new companies are successfully mushrooming with their line-up of potentially disruptive technologies (in the areas of batteries, charging infrastructures, communication technologies, etc.).

Amidst all this dynamism on the R&D front, there has hardly been any significant move towards actual deployment, much owing to significant cost, technology and market-creation challenges and a resultant reluctance of global OEMs to introduce such vehicles in the market (some exceptions exist, of course). As a result, with lacking production commitments from global OEMs (see Figure 2), other actors who are investing in developing technologies pertinent to electric vehicles are eagerly seeking partners to deploy their technologies as products-on-the-road. This has created opportunities for OEMs from developing countries looking for knowledge linkages to build their development competence and product portfolios. The Indian automobile industry presents examples of such linkages developing in the recent years both in the broader automobile industry as well as in the specific context of EV technologies.

Figure 2: Global government targets and EV/PHEV production/sales/targets reported by OEMs



Source: IEA EV/PHEV Roadmap 2011

2.3 Section summary

This section presented the basic underpinnings of electromobility while highlighting the various technological, financial and infrastructural dimensions of the technology and the positioning (and its underlying motivations) of different actors (including policymakers, firms etc.). It is clear that the story of electromobility is one marked by technological challenges, firm strategies and one of a sector that requires strong policy support.

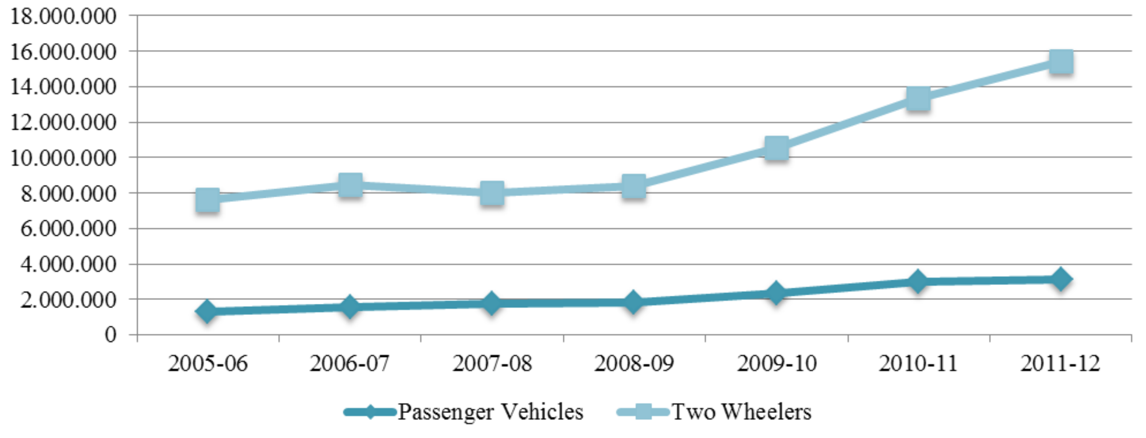
3 The Indian automobile industry landscape and electromobility experiments

Having developed an understanding of the electromobility technology and the global efforts around it in the previous section, this section provides a brief background to the Indian automobile sector – the broader ecosystem within which the Indian electromobility trajectory is developing. Also highlighted are the policy framework and structural issues such as power infrastructure that are likely to shape the Indian electromobility trajectory.

3.1 The Indian automobile landscape

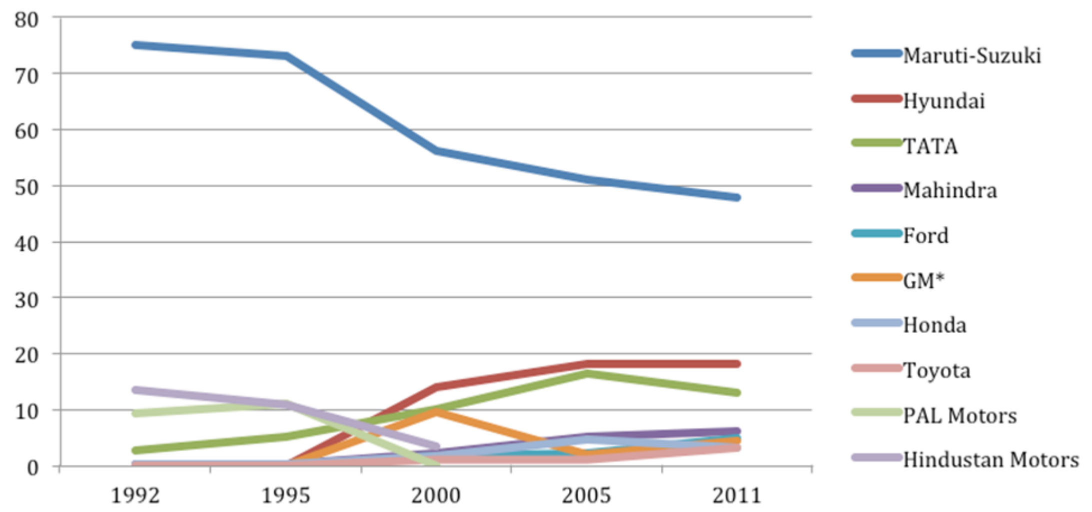
India has become a major automobile manufacturer, producing almost 3.3 million cars and over 13 million two-wheelers in 2012 (see Figure 3), with all the other segments (three-wheelers, commercial vehicles etc.) in the automobile sector registering impressive growth figures as well (OICA estimates, ICRA 2012). With sustained high growth over the past decade, the Indian car industry, which represented just 1.69% of the global car production figures in 2002, has grown to a 5.2% global share in 2012 (OICA estimates). At the same time, India has also become the second largest two-wheeler market in the world, closely trailing China.

Figure 3: The production of two-wheelers and passenger vehicles in the Indian market



Source: SIAM (www.siamindia.com)

Figure 4: Market share of OEMs in the Indian market over the past 15 years



Sources: Company Annual Reports and SIAM reports

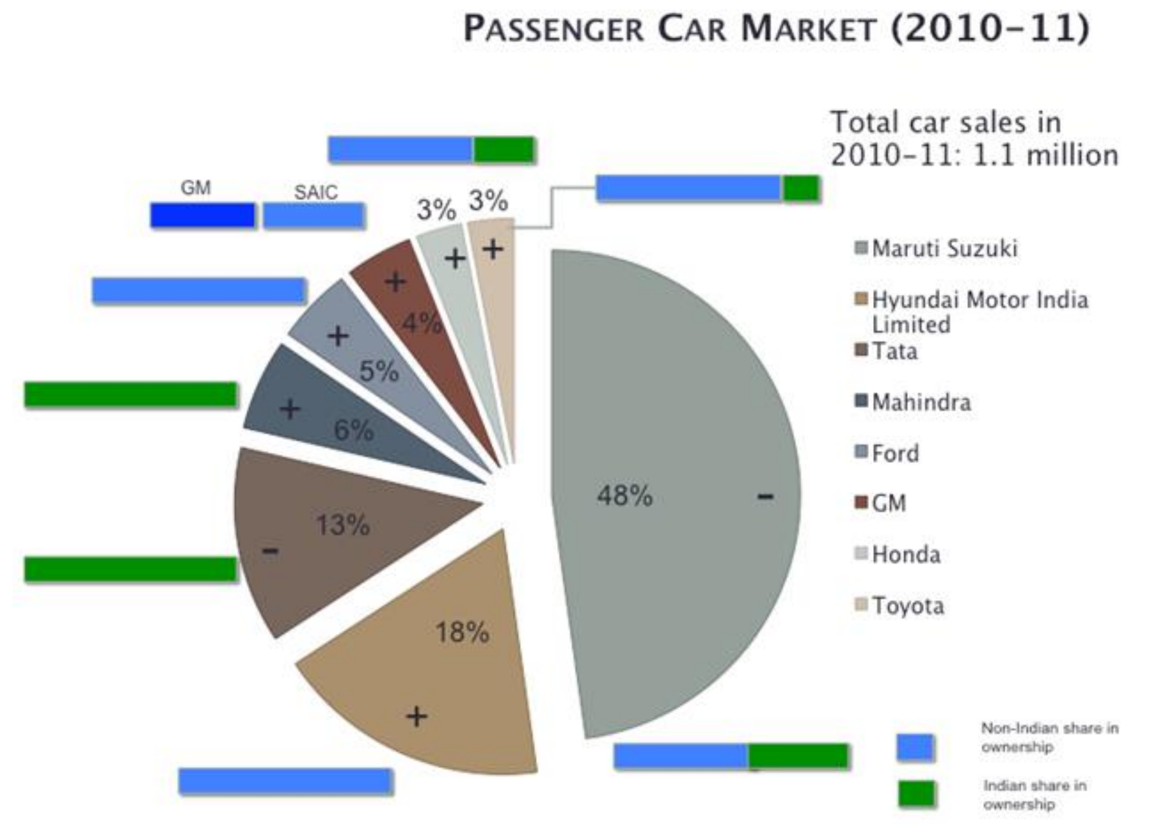
3.1.1 The Indian passenger car industry

Over the past decade, the structure of the Indian car industry has undergone a shift with an increase in the number, size and engagement level of the OEMs, both global as well as domestic, with concomitant advances occurring in the technological capabilities of the underlying innovation system. Still, unlike the Chinese car market, where almost 150 original equipment manufacturers (OEMs) of various sizes exist, the Indian market has relatively few players that dominate the market (see Figures 4 and 5).

Interestingly, the technology gaps between Indian and global products in the ICE sector have been continuously decreasing; a significant catch-up has already achieved (Balcet / Ruet 2011). For example, Figure 6 illustrates the decrease in the time lag between car model introductions in the Indian market versus the international market. International knowledge linkages through knowledge transfer/sharing with Indian subsidiaries by global OEMs or similar arrangements with Indian partners (e.g. Maruti-Suzuki, Tata-FIAT, Mahindra-Renault etc.) have contributed significantly to this catch-up. At the same time, domestic players such as TATA, Mahindra etc. have also invested in in-house R&D and knowledge acquisition through JVs and foreign acquisitions (TATA acquired Jaguar Land Rover and several other OEMs in foreign markets while Mahindra acquired Ssangyong Motors – a major South Korean OEM).

The growing global focus on more efficient cars (compliance with the increasingly stringent efficiency standards is one reason) has meant that for global carmakers there is a certain convergence between their global focus and the Indian market needs: small, efficient cars are in demand (Anderson 2011). During the latter part of the last decade, global as well as Indian OEMs have positioned India as the manufacturing hub for small cars, and exports have grown to almost half a million passenger vehicles in 2011–12, trebling in less than five years (SIAM estimates).

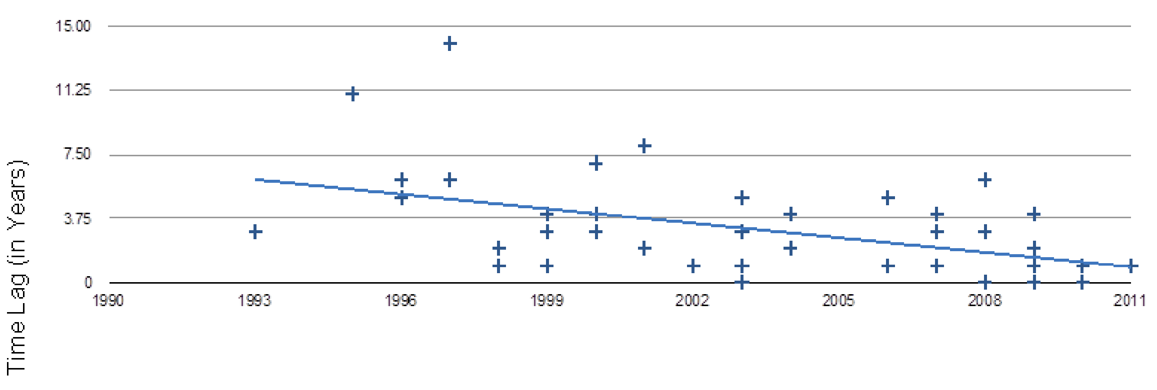
Figure 5: Market shares in the Indian passenger car market with the ownership status of the different firms



The +/- sign represents whether the market share of the company has been increasing or decreasing over the past two years
Companies with a market share smaller than 2% have not been included here, e.g. Volkswagen India and FIAT India

Source: SIAM reports, Annual Reports of firms

Figure 6: The time lag between the global and Indian launches of a particular car model over the years (based on engine version)



Source: Company Annual Reports, Press Releases and product information pages

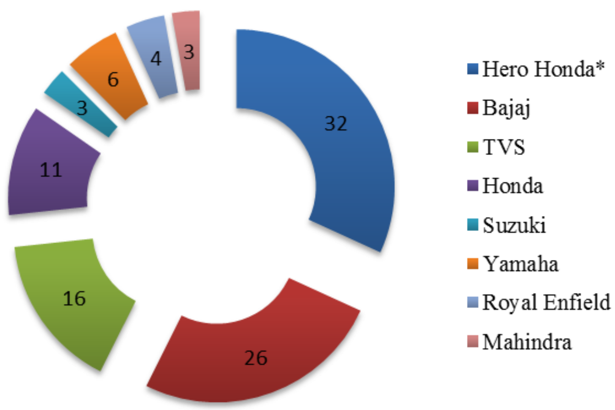
In turn, having developed strong in-house R&D and knowledge linkages through joint ventures (JVs) and acquisitions (see Balcet / Ruet 2011 for more details), Indian OEMs are now focussing on expanding their presence in foreign markets while strengthening their domestic dominance. It is interesting to see that automobile sector R&D spending in India is highly skewed towards the domestic firms; the Indian subsidiaries of the global OEMs spend primarily on acquiring technical know-how from the parent companies (through licensing fees).

Globally, the introduction of emissions control norms has resulted in stimulating technology development in the automobile industry; similar changes have also taken place in India, with tighter controls resulting in the introduction of more efficient engines. The first vehicular norms in India were introduced in 1989, followed by a tightening of the standards and 1991, 1996 and 1998. These control norms were followed by introduction of 'Bharat Stage (BS)' norms in India; the BS-II, BS-III norms have been recently tightened to BS-IV norms, mandating the introduction of cleaner and more efficient technologies, an important signal for encouraging technology upgrading (Sagar / Chandra 2004). Meeting these norms has entailed the introduction of technologies such as fuel injection, multi-valve engines, catalytic convertors, on-board integrated circuits (ICs) and fixed exhaust gas recirculation (EGR). At the same time, policy support for testing and homologation has also helped the Indian automobile industry to develop its technological capabilities (Sagar / Chandra 2004).

3.1.2 The Indian two-wheeler industry

In the two-wheeler segment a story similar to the car segment has unfolded in terms of high growth, better technologies and an R&D focus of the domestic players. However, unlike the passenger car market, domestic players dominate the two-wheeler market (see Figure 7). Further, even in terms of the products offered the India two-wheeler market is very different from the international market dominated by the Japanese and European multinationals. While the international market is focussed on high performance two-wheeler vehicles, low performance vehicles almost exclusively dominate the Indian market, with a high focus on fuel efficiency.

Figure 7: Market shares, 2010–2011, in the Indian two-wheeler market



* Hero Honda is now Hero Motor Corp with the JV ending in 2011

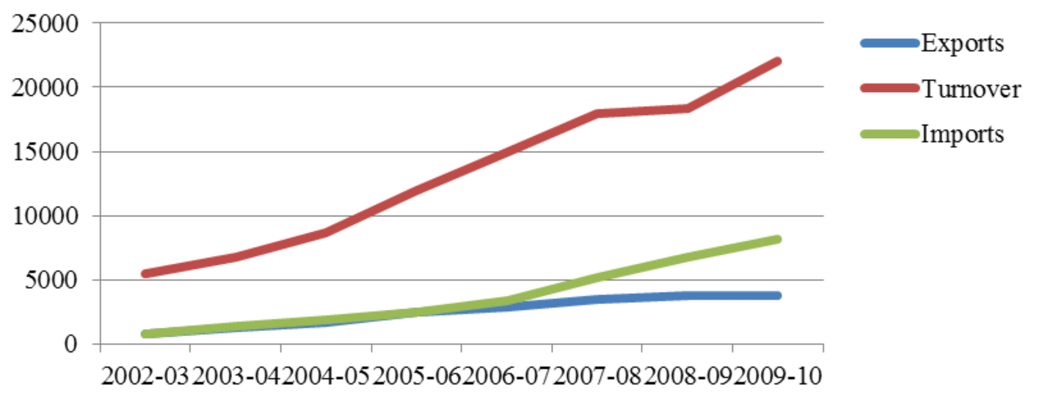
Source: SIAM 2011

As a result, while global players like Yamaha, Suzuki and Honda are present in the Indian two-wheeler market, none barring Honda has been able to make any significant inroads. This mismatch between the technical strengths of global OEMs (high performance vehicles) and the Indian market requirements (low performance – high efficiency[8]) has provided a competitive advantage to the domestic manufacturers. Leveraging this dominance, the domestic two-wheeler OEMs have built significant competence within this vehicle segment over the past decade by investing in in-house R&D as well as knowledge linkages through JVs and firm acquisitions in developed markets.

3.1.3 The Indian auto-component industry

The presence of a large automotive component manufacturing industry in the country, which had a USD 39 billion turnover in 2011–2012 (The Hindu 2012b), has aided the growth of the domestic automobile industry, high degrees of domestic component sourcing helping OEMs to achieve better cost and process efficiencies while at the same time knowledge sharing is facilitated across the innovation system. The recent growth in the auto component sector (see Figure 8) has been marked by increasing integration of the Indian auto component makers in the international automobile industry supply chain.

Figure 8: Growth in the Indian auto component market over the past decade. All figures in million USD



Source: ACMA reports

The domestic component manufacturers have also leveraged acquisitions and partnerships abroad and added to their technological know-how and product portfolios, although their in-house R&D has only recently started to emerge significantly. With the growing presence of global component manufacturers (with strong linkages to the global automobile markets), the Indian component manufacturing industry is also becoming a sourcing hub for global OEMs – almost all major global OEMs (upwards of 20 in 2008) have set-up international purchase offices (IPOs) in India. This integration of the Indian component manufacturing sector in the global automobile supply chain has led to a rapid

8 According to the IEA's technology roadmap for fuel economy of road vehicles, vehicles in India (both two-wheelers and four-wheelers) have the lowest fuel consumption for every 100 kms. travelled in the reported countries.

proliferation of global technology and process standards in the domestic market (IBEF 2008). Meanwhile, the cost advantages of outsourcing engineering design services have made major global OEMs shift these functions to specialized firms in countries like India (IBEF 2012), leading to increased domestic capabilities in the Indian automobile innovation system.

3.1.4 Recent investments and strategic direction

Following the decade-long growth in the Indian automobile market, two recent trends have been strengthening in the growth trajectory. To cater for the growing demand for diesel engines in the domestic market[9], the OEMs (global as well as local) have set up diesel engine manufacturing capacities in the country. In parallel, there is a more general flow of investments in manufacturing capacity. For instance, Suzuki, Volkswagen, Toyota, GM, Ford, Honda, Mahindra etc. have invested in manufacturing capabilities that would bump up their overall capacity by 40–200% of their 2012 capacities (in India) over the next four years.

At the same time, manufacturers such as Honda and Ford are placing more emphasis on product development for the Indian market rather than a mere contextualization of existing vehicles in the global portfolio. Moreover, there is a growing interest in bigger cars and greater fuel efficiency in smaller cars in India (Wonacott 2009). While the former has led to the introduction of several SUV category products, the latter has resulted in weight savings as well as the introduction of newer engines and technologies such as turbo-boost engines, advanced transmission systems etc. There are indications that global OEMs are gradually introducing efficiency enhancing technologies that include some hybridization technologies as well.

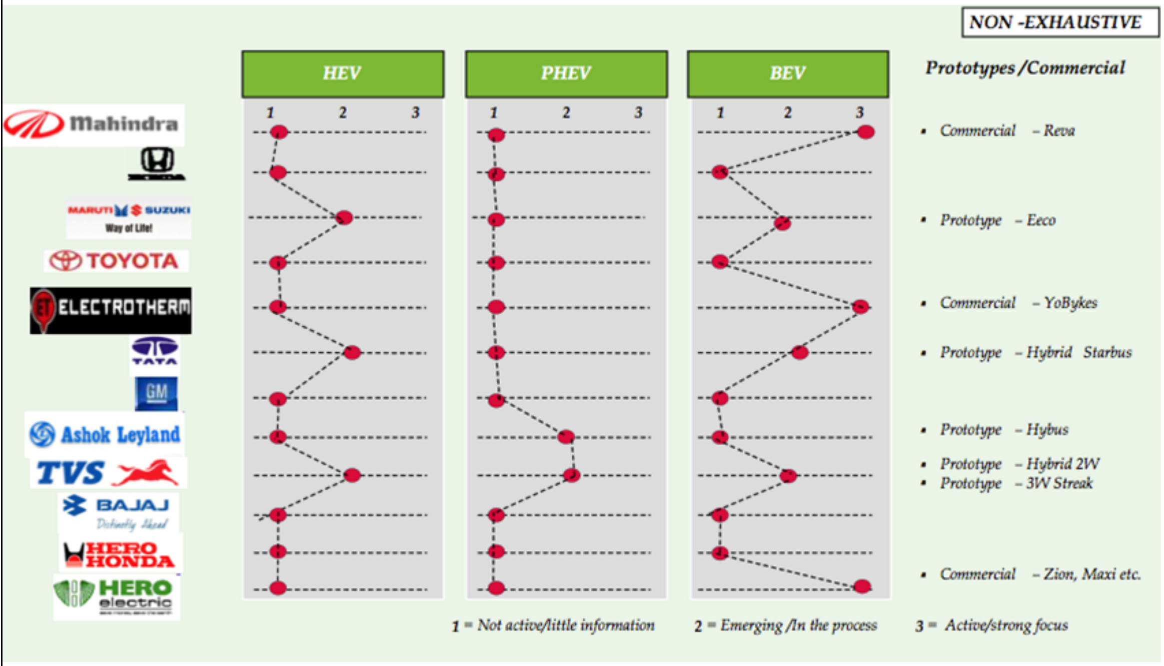
Given the limited convergence between local and global markets in the two-wheeler segment, global OEMs are increasingly keen on penetrating the Indian market while the domestic firms are looking to expand their domestic market share and exports to other developing countries.

The engagement of the two-wheeler and four-wheeler OEMs in EV manufacturing has been quite limited. With a majority of development still at the prototype/pre-commercialization stage, most OEMs have hedged their technology bets by exploring both hybrid and pure BEV product development (see Figure 9). In the four-wheeler domain, while TATA has been working on the HEV and BEV drivetrains, Mahindra, through its REVA subsidiary, has invested significant capital in BEV technology and more recently in hybrid technologies through in-house R&D spending. More specific product development details are presented in section 4.

---

9 In the Indian context, the running cost of diesel vehicles (due to a government subsidy on diesel) is typically 50% of an equivalent petrol vehicle. On the other hand, the upfront acquisition cost of the diesel vehicle is approximately 20% higher than petrol vehicles. Depending on the usage intensity, diesel cars therefore make economic sense for a large number of Indian buyers, resulting in a very strong demand growth for such vehicles.

Figure 9: OEM development activities in various EV related powertrains in India



Source: NEMMP 2020; substantiated and triangulated by interviewees from SIAM, TVS, TATA Motors, ACMA, Mahindra REVA, Hero Electric, TIFAC and IIT Delhi

From a strategic viewpoint as well, the perception of EVs by both Indian four-wheeler and two-wheeler manufacturers has been limited in scope. While the domestic two-wheeler OEMs see hybrid technologies as attractive supplements for enhancing the efficiency of IC vehicles, the pure BEV two-wheelers are understood to be impractical without significant government capital subsidy support. Similarly, the domestic car makers also look at the hybrid technologies as tools for competitive advantages in the IC sector (through enhanced efficiency), although their opinion of the pure BEV segment is slightly more strategic and globally focussed (as manifested in the multiple R&D development programmes being undertaken by them) than their two-wheeler sector counterparts. The global OEMs have shown little interest in the Indian EV market so far and – in the absence of a effective government policy – profess the absence of any strategic outlook for the future as well. More details on these strategic developments in section 4.

From the viewpoint of Indian component manufacturers, a key advantage is the availability of cheap skills (as against cheap labour) in the Indian market. For instance, due to a large supply of skilled, low-cost engineers, firms such as Bharat Forge have very few blue collar jobs: it can afford to employ engineers in almost all positions, leading to a rise in innovation and productivity. Indeed, some suppliers, especially in the power electronics and control systems domain, use electromobility as an opportunity to move from being suppliers to becoming solutions providers. Nevertheless, several gaps in the technological capability of the Indian automotive suppliers remain and the local component manufacturing capability across EV sub-systems is very limited. For example, although battery makers like Exide supply lead-acid batteries for conventional vehicles and also provide for the lead-acid battery packs for REVA (the sole EV maker in India), they are still unable to manufacture lithium-ion and other advanced chemistry batteries domestically.

3.2 Market conditions

3.2.1 Evolution of the automobile market

The Indian automobile market, while growing strongly over the past decade, has also evolved in terms of consumer preferences, available product offerings, as well as technology choices**.** Some of the interesting developments are elaborated below:

Availability of low cost finance: An interesting facet of the growth in Indian automobile numbers has been the availability of finance. Unlike China, where 80% of the car purchases are made in cash, vehicle purchases in India have mainly been credit based: with almost 75% purchases financed on credit, India comes close to the 80% for the UK and US. With the rapid increase in access to banking and credit for Indians (aided by growing incomes), more households have been able to afford a vehicle.[10]

Gradual shift to higher segment passenger vehicles: It is important to note that there has been a significant dispersion in terms of car segments and geographical distribution. Over the past decade, the mini car segment (see Table 3) has been shrinking in size while the compact car segment has been growing rapidly, having become the largest market segment.

Emergence of two-vehicle families: Rising disposable income levels and changing life styles, especially in the metropolitan areas, have resulted in purchases by persons who already own vehicles; there is a trend towards two-vehicle families. Users buying a second car account for almost 40% of the market and a large number of these second cars are small cars (IBEF 2008).

Table 3: Car market segmentation based on size and their respective market shares in 2001–2002 and 2008–2009

Segment	Description	Share in 2001–2002	Share in 2008–2009
A	Mini cars, up to 3400 mm length	28.0%	4.0%
B	Compact cars, between 3401–4000 mm length	54.0%	72.5%
C	Mid size cars between 4001–4500 mm length	17.0%	19.8%
D	Executive cars between 4501–4700 mm length	0.2%	2.8%
E	Premium cars between 4701–5000 mm length	0.9%	0.7%
F	Luxury cars - above 5001 mm length	0.0%	0.1%

Source: SIAM Reports

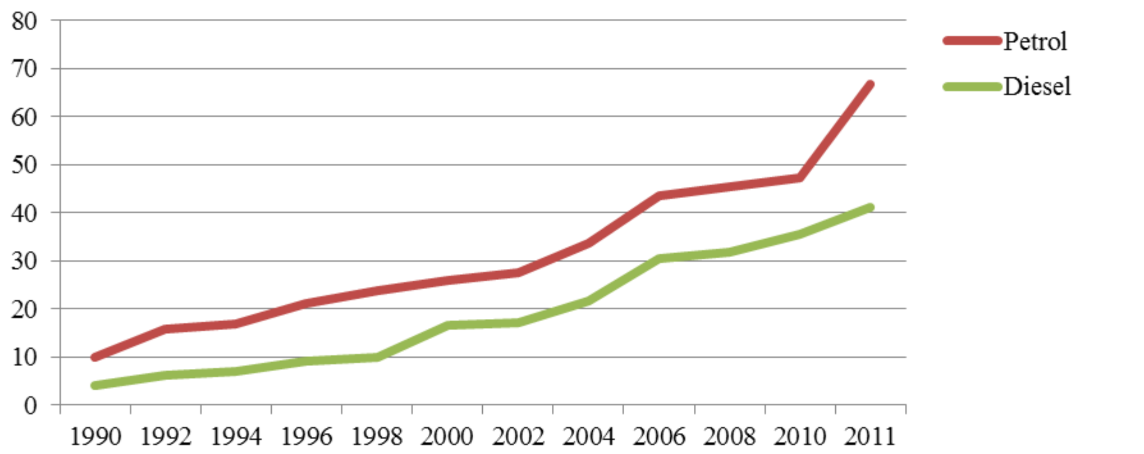
Availability of a wider range of products: The number of players as well as the number of products has dramatically increased over the past decade, making more options available to the end customer: cars are available for almost every budget above INR 125,000 (approx. 2,000 USD). While there were eight to ten major OEMs until the late 80’s, today there are more than 30 OEMs offering a wide variety of products.

10 See: http://www.unido.org/fileadmin/user_media/Publications/RSF_DPR/WP162009_Ebook.pdf.

Fuel preference shift: An interesting trend in the Indian car market is the recent scramble to introduce diesel variants of car models, a measure necessitated by the increasing price differential between petrol and diesel. Over the last six months, car makers have cited high petrol prices (see Figure 10) as a reason for slower demand in the car segment. With government signals towards further deregulation of the petrol and diesel pricing, the cost of vehicle operation may increase even further in the coming years.

Emergence of tier 2 cities and non-metropolitan areas: There has been a gradual shift in vehicle sales to smaller cities as a result of increasing per capita income in these. While the metropolitan areas accounted for a 60–70% share in the number of cars sold in 2001, markets other than the top 20 cities have accounted for almost half the share of vehicles sold in more recent years (IBEF 2008).

Figure 10: Rise in petrol and diesel prices in India over the past two decades (price per liter in Indian rupees)



Source: Newspaper reports for price hikes in this period

Increased product and technology awareness: An important trend in the Indian automobile market is the increasing consumer awareness about automobiles. The advent of websites, TV shows and magazines dedicated to the automobile sector has resulted in an increased awareness amongst consumers, making them more demanding in terms of their technological preferences. The increased awareness has also helped the consumers to understand technology, which in turn has become a determinant of their choice of car, providing a strong *guidance for search* signal to the manufacturers.

High growth in the two-wheeler segment: In the two-wheeler segment, which represents over three-fourths of the Indian automobile market, there has been phenomenal growth over the past two decades. With a vast majority of people unable to afford a car, the surge in mobility has been dominated by two-wheeler purchases. The total sales of the Indian two-wheeler industry have grown at a compound annual growth rate (CAGR) of 13.5 per cent between 2001–2002 and 2010–2011. Further, of the total sales of 13.37 million units in 2010–2011, over 1.5 million were exported (SIAM Reports).

3.3 Electromobility focused policies

From an Indian policymaker's perspective, the deployment of EVs in India offers four broad advantages:

- Reduced oil dependency
- Job creation and economic development
- Reduced urban pollution
- Lower GHG emissions

Of course, this deployment is fraught with challenges in the form financing the capital subsidies for such vehicles, the development of a charging infrastructure and supporting R&D for this emerging technology. While some of these issues are shared globally, there are others, such as the electricity supply situation (see box at the end of this section), that are specifically Indian and shape policymakers' perspectives on this emerging sector.

During the past decade the focus of government policy support to the automobile sector was on ensuring expansion and job growth. The limited numbers of EVs sold were not considered worthy of policy intervention, either through regulation or support. However, by the late 2000s a number of factors changed this perception and led to the announcement of EV-focussed policies. First, REVA sold a majority stake to Mahindra, one of the largest industrial conglomerates in India, with a strong automobile sector presence, possibly leading to a more favourable lobbying position for REVA (and by association for the EV sector) vis-à-vis the government. Second, with India's increased engagement in the global climate change negotiations, climate change mitigation became integrated in the policymakers' motivation mix (Dubash 2013). Finally, the growing global interest in this technology, coupled with India's mounting oil import bill (made worse by the significant devaluation of the Indian rupee during 2008–2013), added a strategic (industrialization and energy security) impetus to policies aimed at electric mobility. A combination of these factors led to a spate of EV-related policy announcements post 2010, although persistent delays in practical action indicate that policy execution is a complex matter.

Some possible factors include the long-term nature of a switch to electromobility (inviting political foot dragging), worsening fiscal deficits of the central government, the slow evolution of electromobility at the global level and the focus of private players on the conventional ICE market. With regard to political foot dragging: Indian policymakers have been quite slow in terms of policy formulation and implementation timelines, even in the case of priority sectors. For instance, while this decade has been proclaimed as the 'decade of innovation' in India, it was only in early 2013 that the first broad draft of an innovation policy was put out by the government. The lack of encompassing manufacturing and R&D strategy moreover results in piece-meal policies governing different industries, with limited synergy and cohesion.[11]

11 Based on inputs from interviewees at IIT Delhi, SIAM, TATA Motors, NSDC and Hero Electric.

More specifically, Indian EV policy has so far been quite limited in terms of its funding and innovation scope: there is a more or less *laissez faire* approach to long-term policy support for the sector. There have so far been two major EV policy initiatives, of which only one has been implemented. In 2010, the Ministry of New and Renewable Energy launched a subsidy for the purchase of electric two- and three-wheelers. During the eleventh five year plan, manufacturers get up to 20% on the ex-factory price of every EV sold up, to a maximum of 100,000 INR per car and 4,000–5,000 INR per two-wheeler. There are higher subsidies for even larger applications in commercial vehicles (see Table 4 for further details). Following that, the government announced a major programme in the form of the National Mission for Electric Mobility under the Department of Heavy Industries in early 2011, with participation from all stakeholders, including the Ministry of New and Renewable Energy, the Ministry of Environment and Forests, the Ministry of Urban Development, industry, academia, etc. The various support options discussed (shortly to be spelled out more clearly) by the National Council for Electric Mobility (NCEM) include purchase subsidies, duty exemptions, income tax exemption, government fleet procurement, R&D support for EV projects, etc. Further, as with the MNRE program in 2010 (which mandated a 30% localization requirement for subsidy entitlement), the NCEM recommendations also encourage local sourcing. With the NCEM recommendations released in the form of the National Electric Mobility Mission Plan 2020 (NEMMP 2020) recommending a government support of USD 3–4 billion for this sector over the next five to six years, the implementation of enabling policies is expected soon (see Table 4 below for more details on the NEMMP 2020).

Table 4: Physical Targets and Central Financial Assistance through the Alternate Fuel based Surface Transportation Programme (AFSTP)

	Type of Vehicle	Physical (units)		Assistance per vehicle
		FY 11	FY12	
Two-wheeler	Low Speed	20,000	80,000	Rs. 4,000/– or 20 % ex-works cost of vehicles whichever is less
	High Speed	10,000	20,000	Rs. 5,000/– or 20 %
3W	7 Seater	100	166	Rs. 60,000/– or 20 %
Passenger Car	4 Seater	140	700	Rs. 1,00,000/– or 20 %
Bus/Mini Bus	>10 seater	–	–	Rs. 4,00,000/– or 20%

Source: http://www.mnre.gov.in/file-manager/new-technology/newtechnology-afstp-12112010.pdf

Of course, given the complexity of the sector under discussion, a range of stakeholders, broader policies (such as investment policies, emissions norms for ICEs etc.) as well as structural factors (see the box on the Indian power sector) are involved in shaping the Indian electromobility paradigm. Annex 1 provides a list of the various relevant policy stakeholders and Annex 2 provides a list of the relevant policies for the Indian EV sector so far (See Urban et al. 2012 for more details).

Box 1: NEMMP 2020 (Highlights)

Target:

- To put 6–7 million EVs on road by 2020; 4–5 million are expected to be two-wheelers.
- Reduce dependence on fossil fuels.
- To promote cleaner technologies.

How will this be done?

- Both the government and the automotive industry will jointly invest INR 230 billion to develop the EV ecosystem in India.
- The government will invest close to INR 140 billion over the next 5-6 years. The car makers will invest close to INR 80 billion.
- India will deploy support measures that will quicken up the process of consumer acceptance of Evs.

Collaboration:

- Potential collaboration opportunities with German and Chinese firms/ research centers to be explored.

An Indo-German Joint Working Group (JWG) on Automotive Sector has been established to intensify cooperation in the development of efficient automotive technologies and alternate fuels and drives.

3.4 Section summary

The purpose of this section was to highlight the broad determinants, including firms, demand conditions, factor conditions and policies that shape the Indian electromobility trajectory. Some important insights emerge from this section. First, the Indian automobile sector players (four-wheeler OEMs, two-wheeler OEMs and component makers) are quite advanced as far as catching up in the conventional ICE market is concerned and are approaching electromobility from a strategic, long-term perspective with investments in in-house R&D as well as building knowledge linkages. The scale and extent of such engagements however, is far lower than those of large global OEMs such as Toyota, GM, Ford, Daimler, etc. Meanwhile, the Indian automobile market presents its own specifics: small vehicle sizes, a large two-wheeler market, a strong preference for fuel efficiency and a burgeoning middle class creating a large demand for personal mobility.

At the same time, from a policy perspective, a mix of priorities is shaping the sector. There are concerns of energy security, job creation and industrialization while at the same time climate change mitigation is also a priority. While these priorities have led to a mission-based policy approach announcement, financial considerations have delayed implementation. Interestingly, as we shall see in the next couple of sections, the private sector has undertaken activities to develop electromobility technologies despite these delays. These have led to some competence areas in various technology sub-systems, as the next section will show which presents the nature of Indian EV trajectory across deployment and technology sub-trajectories as well as network linkage dimensions, and where we look closer at the sectorial innovation path in this sector.

Box 2: The Indian Power Sector

An average Indian household consumed 879.22 KWh of electricity in 2011-12, with over 300 million individuals still isolated from the electricity grid. To put things in perspective, compare this figure with the 1000 KWh that a REVA E2O car would require to run 10,000 kms. Moreover, electricity is in critically short supply, with a peak electricity shortage of almost 16.6% (in the southern grid) and poor grid resilience in spite of the fact that a quarter of the population has no electricity. The peak electricity shortage is growing because the increase in demand far outstrips the added generation and because of phenomenally high transmission and distribution losses (~25%). Against this backdrop, any sizeable BEV/PHEV deployment remains a contentious and difficult undertaking. (Source of power consumption, peak shortage and T&D losses data: http://www.cea.nic.in/reports/monthly/executive_rep/jan13/jan13.pdf)

The key virtue of EV from a climate change mitigation viewpoint is the emissions reduction of our vehicles. Of course, this is a simplification. The exact difference in emissions between an electric drivetrain and an ICE depends on the carbon content of the electricity powering the EVs. In the Indian case, the emissions of 370 g CO_2-e /Km for EVs (as studied by the reference report – Shrink That Footprint, 2013) far exceeds the typical fleet emissions of approx. 140 g CO_2-e /Km for the ICE cars. This high carbon content of electricity is a direct result of a coal-intensive power generation mix as well as the high transmission and distribution losses (the coal intensive power generation is also a problem in other developing countries, including China). More importantly, this high coal power dependence is projected to continue for at least a couple of decades, clearly implying that in the absence of a linkage between EV deployment and renewable energy for powering them, EVs would not contribute much to climate change mitigation until 2030–2040.

This power sector externality is a strong factor in determining the potential for BEV/PHEV deployment in the country. However, for the HEVs (excluding PHEVs) this externality is not an issue: they require no electricity, and this is a factor favouring the deployment of these vehicles.

4 Emerging sector innovation pathways in India

The previous section provided a bird's eye view of the overall environment within which the Indian electromobility trajectory has only just begun to emerge. In this section we zoom-in on the electromobility trajectory and try to draw some characterizations. We begin with looking at what deployment action has so far materialized within the sector, followed by a discussion on the supply-side developments in terms of research, development and capability building across various technology sub-systems. For this, we look at the investments both within in-house R&D as well as those that develop knowledge linkages (domestic as well as international). Towards the end, we point to the Indian trajectory's direction along the core-technology leanings, vehicle types and charging infrastructure dimensions.

4.1 Major activities

4.1.1 Production of EVs

Long before the present wave of interest in electric vehicles, India had an electric car available domestically. The REVA compact electric car, launched in 2001 for sales in India, drew components and technologies from a range of suppliers in the US along with design and development assistance from a California based firm. However, owing to a number of reasons, including low market acceptance of a new technology, high battery costs, limited range and a lack of any government support, the car saw a muted response in the Indian market. Interestingly, the same product saw a better acceptance in the UK market due to favourable tax and rebate policies. While improvements were made to the REVA with each consecutive model (the most noticeable being the REVAi in 2008), the sales of the vehicle, which utilized lead acid batteries and had a range of only 80 Kilometres, remained low. By 2012, when the company ceased production of the REVAi, India's sole representative in the EV passenger vehicles category, it had sold less than 5,000 units worldwide, a sizeable fraction of these being exports. Estimates of present EV stock in India are around 1550 vehicles (IEA 2013). Following this seeming debacle, Mahindra – one of India's leading OEMs – acquired a majority stake in REVA. REVA's next generation of EVs, the REVA NXR (recently rechristened REVA E2O) has been widely showcased and a 30,000 cars a year capacity plant has been put in place. However, the actual sales of the REVA E20 – launched in March 2013 – have been poor, owing to, among other things, the delay in announcement of the capital subsidy provision for EVs in India.

In the two-wheeler EV domain the production of vehicles has so far been limited to the assembling of kits imported from China, with a cycle of boom-and-bust over the past five years. Starting in 2008, over 20 firms, mostly without any prior experience in the two-wheeler industry, undertook the assembly and sales of two-wheeler EVs. However, within three years the sales decreased substantially (despite capital subsidy announcements by the Indian government) as poor service provision by the numerous assemblers and high maintenance costs (initially underestimated) drove the customers away. It is interesting that even though some major OEMs in the two-wheeler domain, such as TVS, also launched two-wheeler EVs, even these were contextualized Chinese EV kits with little manufacturing Indian content that were rather quickly abandoned by the Indian customers due to the high battery replacement costs. As a result, while over 300,000 vehicles have been sold so far, the numbers of vehicles in use are reportedly much lower[12]. At present, while some of the remaining sellers of the original two-wheeler EV wave remain, operations in India primarily consist of imported kit assembly. Some players such as TVS have completely moved away from the pure battery two-wheelers and have concentrated their efforts on developing hybrid two-wheelers suited for the Indian market.

In other automobile categories, such as commercial vehicles, no EV production or sales have as yet materialized within India.

4.1.2 R&D across various sub-technologies

As already highlighted in section 2, electric vehicles have a number of complex sub-systems. In the Indian case, the research and development efforts of the players have been spread across the various sub-technologies, with substantial progress and capability development in some technologies while lagging technological prowess mars some others. Below is a brief overview of the development efforts across the different major sub-technologies, highlighting the stakeholders as well as the perceived level of competence in the respective technologies.

---

12 Exact numbers not available. Confirmed in interviews with senior management of leading two-wheeler manufacturers in India.

Body and chassis

The past decade has seen the Indian automobile industry develop its product design and development capabilities significantly through technology licensing, strategic alliances, acquisitions and increased R&D investments. As a result, while the product developments a decade ago (such as the TATA Indica) relied heavily on design and technology assistance from abroad, more recently, developments such as the TATA Nano and the Mahindra XUV500 have relied almost exclusively on in-house or local firm resources. Of course these developments have relied on components and systems sourced from foreign suppliers; however, unlike a few years ago, the development process has been realized in-house. For EVs, in recognition to the limited power densities of existing battery technologies, it is imperative that the vehicles are lightweight. Yet, to get regulatory approvals, the vehicle needs to be designed with the safety aspect in mind, and designing a safe, lightweight vehicle is a challenge.

Drawing on the past decade's learning in vehicle body design, Indian EV makers like TATA, TVS and Mahindra have created designs and developed prototypes comparable to global EV developments in terms of low weight and safety measures. Further, the REVA E2O uses a space frame construction, which involves a skeleton-type structure as opposed to traditional ground-up construction (such as body-on-frame construction). The space-frame approach, while providing for cost savings (lower capital costs to set up manufacturing) and low weight, presents challenges such as lower body strength and difficulty in mass production. But even though conventional car makers use body-on-frame construction to manufacture ICE vehicles on large scale, REVA has opted for the space-frame approach. In the two-wheeler domain Indian OEMs have also demonstrated a good understanding of vehicle design and dynamics optimization owing to their long experience in developing ICE powered vehicles.

Electric drivetrains (including motors and controllers)

The nature and technological complexity of electric drivetrains varies significantly across the various EV types. Even in the hybrid vehicle category drivetrains can be broadly characterized as parallel, series and power-split drivetrains, each with their specific component arrangement. The Indian OEMs in the four-wheeler as well as two-wheeler domain have demonstrated a capability to design and manufacture drivetrains of varying complexity, ranging from the pure EV drivetrain for the REVA E2O to the series hybrid drivetrain of the TATA prototypes (Pixel etc.) and the power-split drivetrain for the two-wheeler hybrid vehicle developed at TVS. That said, the optimization of power consumption (and regenerative power capture) requires advanced control systems, and despite the close linkages of the domestic OEMs with the Indian electronics and information technology (IT) firms working with global OEMs, it is not clear if the Indian EV drivetrains match up to the international standards of technological advancement.

R&D by Indian electric motors and controller manufacturers for the various components has however been limited; they are still working on contextualization of the existing technology to the needs of EVs. For instance, while the motor suppliers for TVS have effectively been able to redesign the controllers for higher current values, the development of better performance motors is still underway, lagging behind the international leaders in

South Korea and Japan. Interestingly, the OEMs are collaborating with the suppliers of these components to develop high performance products for their EV programmes. At the same time, the OEMs (including Mahindra, TATA, TVS, Hero, etc.) are also developing relationships with the international suppliers of these components to have access to better technology while the Indian suppliers catch up. For instance, while working on EV development, TATA collaborated with A123 systems of the United States to develop battery cells for their prototype vehicles.

Battery cells

The low performance and high cost of battery cells pose perhaps the most challenging problem for the large-scale deployment of EVs. Indian battery cell manufacturing capability is limited to lead acid batteries; all the Li-ion cells are imported (primarily from China, South Korea and Japan). The existing lead acid battery manufacturers have shown limited interest in entering into local manufacturing of Li-ion or NiMH battery cells. In recognition of the high investments in creating the supply chains for the advanced battery chemistries and developing the technology know-how, even the proposed NEMMP does not envisage any significant battery cell R&D in India over the short to medium term. Instead, it proposes a technology acquisition and global partnership model for increased technology access. However, the plan does propose the development of domestic battery manufacturing on the basis of imported battery cells, and outlines measures to promote R&D in this part of the battery supply chain.

At present, all the players in the EV domain in India are importing battery cells from China, South Korea and Japan, while at the same time collaborating with American firms on basic battery R&D, albeit on a very limited scale. Some government research labs like Central Electrochemical Research Institute are undertaking research in advanced battery chemistries; however, there is little evidence of any breakthrough or industry collaboration.

Battery management system (includes pack development, thermal management, electrical management)

A strong innovation system characterizes the power electronics, control systems and IT sectors in India. A large part of these capabilities has been developed as a result of work outsourced by global firms in these domains or the research centres established by these firms in India. Coupled with the fast developing in-house capabilities of the Indian OEMs, this has led to a strong advantage for the Indian industry as far as the battery management systems are concerned. These systems, which play a crucial role in optimizing the performance and ensuring the safety of EVs, also represent an important cost element in EVs. Interestingly, the development of battery management systems (BMS) has not been restricted to the OEMs. Technology solutions providers like the KPIT have also developed BMS (not yet commercially deployed) that are available for competitive licensing. The success potential of such independently developed systems is however not clear. What is clear, though, is that having co-developed several on-board systems with global and domestic OEMs, Indian suppliers in this domain have developed a significant expertise, also in managing such relationships.

Connectivity (includes telematics, communication, analytics etc.)

An interesting phenomenon in the Indian automobile industry in recent years has been the introduction of fringe technologies and features that are common to high-end cars in the global markets in cheaper cars. This phenomenon has led to the development of affordable solutions around value-added services such as GPS-based Satnav systems. Further, the presence of a flourishing IT industry has meant that connectivity solutions such as monitoring, telematics, communication and analytics gathering are easily available , lowering the development costs of adding such features to EVs. While these features are not part of the core technology that drives the EV, given the uncertainties of a nascent technology and limitations of vehicle range, these could provide a strong differentiating factor for the EV products offered. Indian EV players seem to have easy access to these technologies and solutions, even though it is not clear if they have invested significantly in these solutions themselves.

To supplement the above discussion on India’s competence in the various sub-systems, an estimate is given in Table 5 of the value of different sub-systems in a typical electric vehicle, juxtaposed with the perceived competence of the Indian players within these. The estimates, derived from the NEMMP 2020 document and substantiated through interviews with key informants in the sector, are useful when considering the industrial and financial implications of electromobility for the Indian economy and innovation system.

Table 5: The relative value of sub-system technologies in a typical EV and the present competence of the Indian ecosystem within these technologies

Technology Area	Value of the sub-system in typical EVs	Present competence of the India Innovation System
Battery Cell	55%–70%	Low
BMS	5%–10%	High
Power Electronics (Control Systems)	10%–15%	High
Electric Motors	5%–15%	High
Transmission	<5%	Moderate

Source: NEMMP 2020

4.1.3 International and national linkages

While international linkages specific to EVs have been quite sparse in the Indian case some specific instances do exist, such as the acquisition of Ultra Motors, a UK-based two-wheeler EV manufacturer by the Hero group in 2011 and the acquisition of Miljøbil Grenland in 2008, a Norway-based specialist electric car maker by TATA. While these instances point to some learning from abroad, no strategic knowledge linkages were developed so far beyond these particular events. In the product development phases, almost all domestic players have international linkages for the battery systems. These linkages have ranged from joint basic research in battery materials to off-the-shelf purchase of components with minor contextualization tweaks.

Table 6: Perceived sub-system competence levels within the Indian automobile industry

Innovation System Components (Across)	Body and Chassis	Trans-mission	Electric Motor	Battery Cell	Power Electronics (Control Systems)	BMS
Perceived Competence (2000)	Low	Low	Low	Low	Low	Low
Perceived Competence (2013)	Moderate	Moderate	High	Low	High	High
Value assition in a typical EV (exact values vary with vehicle)	Low-Moderate	Low-Moderate	Moderate	High	Moderate	Moderate
Global Linkages or R&D	Moderate	Low	Low	Low	High	High
Major Influencing Factors	Acqui-sitions and Joint Venture learning by OEMs	Source follow by global players, global integration of domestic suppliers	Source follow by global players, global integration of domestic suppliers	Lack of manu-facturing investment interest and policy support etc.	Growth of IT and electronics design outsourcing industry, global R&D centers of Electronics majors, cheaper engineering talent	Growth of IT and electronics design outsourcing industry, global R&D centers of Electronics majors, cheaper engineering talent
Involved Players	OEMs	Suppliers	Foreign and domestic suppliers	Foreign suppliers	OEMs and suppliers	OEMs and suppliers

Source: NEMMP 2020 and inputs from interviewees at TIFAC, SIAM, TVS, Mahindra REVA, KPIT Cummins, ACMA and NATRiP

The last decade has been a period of high growth for the Indian automobile market. Interestingly, domestic Indian players like Tata Motors, Mahindra & Mahindra, TVS Motors and Bajaj Auto have been able to leverage this high growth period to build strategic competitive advantages in the market. These players have effectively moved from being importers of foreign technology to product developers. This has been charted through an extensive learning phase characterised by in-house R&D spending, strategic alliances, JVs (Tata Motors with Fiat, Mahindra & Mahindra with Ford and Renault, Bajaj Auto with Kawasaki, and TVS with Suzuki), acquisitions and assets-building efforts in foreign markets (Jaguar Land Rover by Tata Motors, Ssangyong by Mahendra & Mahendra, and KTM by Bajaj Auto) as well as knowledge linkages with research centres, technical institutions, suppliers and smaller firms in foreign markets. In addition to technology provision advantages, these developments have also improved Indian manufacturers' reach into global markets. Several of these linkages have also contributed to improvements in the EV domain. For instance, better vehicle design capability, an improved understanding of hybrid powertrains as well as better systems integration knowledge have all contributed to the ability of Indian OEMs to produce better EVs. However, in the national EV ecosystem, the domestic linkages have not extended beyond the existing linkages in ICE vehicle manufacturing. The OEMs have partnered with the same domestic suppliers (except for batteries, which in any case are imported) that have traditionally been associated with these OEMs. For instance, TVS has worked with the same control system manufacturers who provide components for their ICE vehicles to develop control systems for EVs, of course with changed technical specifications. Similarly, Revolo and Bharat Forge have traditionally worked to develop technology solutions for OEMs and have extended this relationship to the EV domain. In the domestic ecosystem, the EV sector has not led to the emergence of any new knowledge linkages but has only expanded the scope of some of the existing linkages. This is perhaps a manifestation of the 'side-kick' perception of EV technologies as an area where a strategic presence has to be maintained but large investments are not warranted because of the lack of deployment potential in the short term.

4.2 Elements of the emerging trajectories in India

4.2.1 Hybridization

Due to several financial, infrastructural and strategic reasons highlighted in section 2, the hybridization route to a partial electrification of the transport fleet has gained traction in India. As illustrated in Table 1, the present portfolio of hybrid technologies extends from simple systems that capture small gains in fuel efficiency by storing energy generated through braking to complex systems that intelligently modulate the power flowing to and from the ICE and electric drivetrains in the vehicle. Through prototypes and concept vehicles, Indian OEMs such as TATA have demonstrated development capabilities extending across this wide range.

Although micro-hybrid technology has been used by some Indian OEMs even in the last decade, the move to higher levels of hybridization has been restricted due to a number of reasons. Despite the demonstrated prowess of Indian OEMs in the development of hybrid vehicles, the additional costs of drivetrain hybridization are widely seen as too high for Indian market conditions.[13] However, this reluctance to introduce a product has not stopped Indian OEMs from investing in research and development in this technology. Major Indian OEMs such as TATA, Mahindra, TVS and tier-1 suppliers such as Bharat Forge have invested substantial capital in hybridization technology over the past three to four years because of the potential of these technologies for efficiency enhancement (especially as battery prices decrease in the future) as well as the increasing strategic importance of electric drivetrains in global markets.

---

13 Most hybrid technologies capture energy through regenerative braking. Lead acid batteries (which are relatively cheap) cannot recharge quickly enough to allow this capture. The other viable technologies – such as Li-ion, NiMH or super-capacitors – on the other hand lead to much higher system costs, rendering the hybridization technologies too expensive for the Indian mass market.

It is important to remember that, while the hardware component of the hybrid technology is important, the control systems (in turn incorporating complex algorithms) add most of the value to the vehicle as the drivetrains have grown complex. These control systems and the systems for thermal and electrical management in the EV are increasingly seen as critical technology components. Most Indian players have developed capabilities – either in-house or in collaboration with the technology solutions companies like KPIT – across these technologies, often accompanied by significant intellectual property (IP) generation.

Interestingly, the presence of strong engineering and development skills outside the major OEMs in India has enabled the development of hybridization kits that could be retrofitted to existing vehicles. For instance, as discussed in more detail in the next section, KPIT Cummins has collaborated with Bharat Forge (one of the largest automotive suppliers in India) to create a hybridization kit for a range of vehicle types and engine sizes without any OEM support.

Considering the gradual ICE technology learning that is expected to continue in the Indian automobile sector and the limited domestic competence in battery technology, there is an inclination towards hybrid technologies in Indian policy circles. While providing cost advantages due to smaller battery sizes (expected to lead to faster market adoption), hybrids do not require public charging, alleviating the need for the associated infrastructure creation. Further, the growing development capabilities of Indian car makers in the conventional ICE segment, as discussed in the previous section, could result in the creation of capabilities for the manufacturing of the complex hybrid drivetrains required for hybrid EVs.

4.2.2 Pure Battery EVs

Policy as well as business circles are much in agreement that, given the present technology, the power sector situation and the large infrastructural investments required, a large-scale deployment of pure battery EVs is very unlikely in this decade. Pure battery EVs, whether they are two-wheelers or cars, will remain a niche market for the time being. In contrast to developed countries, these vehicles are therefore being engineered to serve as replacements with specific use patterns (intra-city vehicles, delivery vehicles, premises-bound mobility vehicles, etc.), not as all-purpose replacements to ICE vehicles. While limiting the market for these vehicles, this approach has mitigated some of the challenges facing EVs because vehicle size, battery sizes and charging times are limited in these cases. Figure 11 illustrates some of these points for Nissan Leaf and Mahindra REVA E2O.

Despite this limited purview, acknowledged by policymakers and businesses alike, pure battery EVs attract the best policy support mechanisms in the form of significantly higher subsidies proposed in the NEMMP. A closer look at the proposed subsidies reveals a strong correlation of the subsidy to the battery sizes in the respective vehicle categories.

It is noteworthy that despite the development capabilities (as demonstrated by the various pilot projects and prototype launches in the past years), none of the major global OEMs or TATA are planning pure EV launches for the Indian market anytime soon. Unlike the US and EU, where stringent fuel economy standards in the coming years appear to be one of the major drivers for the interest among OEMs for EVs, the standards for fuel consumption proposed by the Bureau of Energy Efficiency in India appear easily attainable by the Indian OEMs (except Mahindra, which interestingly is the only active carmaker in the Indian EV market through Mahindra REVA) (link to the CSE study[14]). It is instructive to note that while the standards proposed by Bureau of Energy Efficiency are in line with the international standards proposed for 2020, most of the Indian OEMs start with lower base emissions in 2012 due to the lighter vehicle weights of most Indian cars.

4.2.3 Vehicle types

The importance of the two-wheeler segment in India has already been pointed out. In 2011, more than three times as many two wheelers were sold than cars. Even in the EV segment, there is much agreement that two wheelers will play a lead role in driving deployment. The NEMMP, for example, projects that almost three-fourths of the electric vehicles sold in India till 2020 will be two-wheelers. This prominence is a result of the large number of potential buyers, the lower power requirement and the lower prices (due to smaller battery sizes and less sophisticated control systems) of two-wheeler EVs compared to ICE two-wheelers. Further, the strong R&D and development capabilities of the Indian two-wheeler OEMs are expected to provide a supply-side push.

4.2.4 Charging infrastructure

The present state of battery technologies has imposed constraints, both financial as well as technological, on the range of a pure EV. As a result, any move towards extending the range of purely battery driven EVs requires an adequate charging infrastructure. However, the huge financial implications of developing such an infrastructure are considered by many to be a major deterrent to EV adoption across the globe. Worldwide, several recharging models, both in terms of the actors and the technology involved, are being tested.

The lack of activity in creating a charging infrastructure in India must be seen in this context. As highlighted above, there is a preference for hybridization technology in India, and this requires a much less sophisticated recharging infrastructure. Further, even in the pure battery trajectory in India the ‘niche-usage’ vehicles are being engineered (with smaller battery sizes) with home recharging in mind. As a result, interest in the development of the recharging infrastructure has been lacking among both private and public players. While the NEMMP recommendations propose the establishment of a public charging infrastructure, it does so in the later phases of the mission, recommending home recharging for smaller battery size EVs and hybrid vehicles.

4.3 Section summary

Having probed the major elements of and trends in the Indian EV trajectory, we can identify some clear points. First, Indian OEMs and component makers have developed capabilities in particular sub-systems, such as power electronics and control systems, while lacking them in

14 See http://www.cseindia.org/content/proposed-fuel-economy-standards-a-complete-sell-out-says-cse for more details

others, most importantly batteries. Second, as a result of the various determinants discussed in the previous section, the trajectory has moved towards hybridization technologies and two-wheelers. Not much attention has been paid to the development of a public infrastructure and its absence is considered a structural limitation by firms in their planning of new products, as the case studies in the next section will show.

5 Innovation case studies

To understand the nature of the Indian EV technology trajectory and the way in which technological or organizational innovation evolves, it is important to get a clear picture of Indian electromobility technology. For this purpose we use three case studies illustrating the specific Indian innovation path. The case studies (selected on the basis of criteria listed in Box 3) provide particularly useful insights into the character and evolution of the EV technology trajectory in India. Each case discusses the technology/process innovation, highlighting its importance in the Indian electromobility trajectory, the innovation determinants and the implications for the future evolution of the trajectory.

The three cases selected, taken together, offer a reasonably complete picture of the sector both in terms of the types of players and the technologies. The Revolo case presents the development of a hybrid retrofit solution by non-OEM players. The TVS Qube case illustrates the development of a hybrid two-wheeler by one of the major OEMs in the segment. The REVA product development study presents pure battery EV development by an outsider to the conventional ICE ecosystem, which however is controlled by a major automobile conglomerate.

Box 3: Case selection criteria

Core criteria

(1) Investment rule

- Substantial investments by market actors
- Close to/targeted at commercialization

(2) Significance for innovation path rule

- Technology or organization innovation that represents an innovation path or an important alternative innovation path
- Excludes single incremental technology improvements
- May include cases in which a combination of a set of incremental innovations at up to a substantial technological / architecture innovation

Additional considerations

(1) Scope rule

The case should have a clearly defined scope and boundary

- In terms of technology / business model (the more specific the better)
- Specific in terms of involved market pllayers

(2) Country specificity rule

The case should be important for understanding characteristics of the country innovation path

(3) Comparison rule

The case should allow for interesting comparison with other countries, either by similarity or by contrast

5.1 Revolo

The existing vehicle fleet in India, as elsewhere, consists of ICE vehicles that depend on fossil fuels, leading to air pollution, GHG emissions and energy security problems. The slow diffusion of EVs means that new vehicles will predominantly have ICEs. KPIT Cummins, India's largest automobile IT /technology services company, has therefore developed a plug-in hybrid conversion kit that has been tested by the Automotive Research Institute of India (ARAI) to provide efficiency improvements of over 35% over a range of vehicles with engine sizes in the range of 800cc to 3,000 cc.

At its core, Revolo is a plug-in (batteries can be recharged externally) parallel hybrid solution that improves the efficiency of an ICE vehicle. The power of the electric motor is tapped for a control system ensuring that the ICE engine works, to the extent possible, in its most efficient running cycles. Further, the system uses intelligent telematics to recognize driving patterns and self-adjusts for better efficiencies.

The kit, initially conceptualized by KPIT Cummins, will be manufactured by a JV (named IMPACT) between KPIT Cummins and Bharat Forge, one of India's largest auto component makers. While KPIT licenses the technology to the JV, Bharat Forge brings in essential manufacturing know-how, assembly capabilities and integration expertise. The expected cost (including installation) of the kit is INR 65,000 (~1,200 USD) to INR 150,000 (~USD 2,800), depending upon the engine size. This cost represents a fraction of the cost of similar hybridization kits developed by firms in the developed markets, where the purpose of the kit is usually not efficiency improvement but power (and acceleration) enhancement by adding an additional power source to the drivetrain. It is noteworthy that the Revolo converts an ICE vehicle into a plug-in hybrid vehicle even though a battery-only propulsion mode is not available; it uses electronic control systems to optimize the operation of electric and ICE power.

India has a small but stable market for compressed natural gas (CNG) kits that provide retrofit options for petrol-driven cars, suggesting a consumer appreciation of retrofit kits. Further, the Indian automobile market has, as discussed, seen a gradual shift towards more fuel-efficient and diesel cars, a likely manifestation of consumer sensitivity to the running costs of petrol-driven vehicles. This could aid the adoption of the Revolo kits that improve fuel efficiency substantially[15] and promise an average payback period of two to three years.

Approximately USD 2 million has been invested so far in the development of this hybridization kit, with over 11 patents granted primarily around control systems and motor design. Interestingly, the hybridization product is battery technology neutral and can be used with different battery chemistries such as lead acid, lithium ion, NiMH etc. As a result, the overall cost of the hybridization kit can vary greatly depending on the cost-performance trade-off required by a specific vehicle, with the flexibility in system design allowing for significant application versatility. At the same time, the partners in the Revolo programme have spent significant capital in the installation and servicing standardization throughout the country.

At present, along with efforts to introduce this as an after-sales kit in the market, there are on-going negotiations with international OEMs for licensing of this entire hybridization

15 Substantiated and confirmed by interviewees from SIAM, ACMA, TIFAC and IIT Delhi.

technology as well as parts of the hybridization solution for foreign markets. Interestingly, KPIT has begun exploring the foreign market: the Royal Malaysian Police is testing the retrofit kit in their vehicles.[16] Indian OEMs, possibly due to their own in-house programmes, have not shown much interest in this hybridization kit product.

Underlying currents

The development of hybridization kits by non-OEMs in India points to the growing development capabilities in supplier firmsy. More importantly, this product also points to the emergence of engineering services companies in India and their partnering with Indian component manufacturers to develop innovative products for the Indian market. At the same time, both types of firm are increasing their international presence – KPIT Cummins has offices in 11 countries.

One of the reasons for the low cost of Revolo, when compared with similar kits available in developed country markets, is the integrated development and high R&D expenditure that has gone into the product. Unlike several developed country market kits that often use components off-the-shelf, most of the components (except batteries) going into Revolo have been extensively redesigned, which makes them cheaper and perform better. Moreover, for hybridization kits, a large part of the value addition outside the battery is in the control system algorithms. Leveraging in-house expertise in developing solutions at the interface of engineering and IT, KPIT Cummins has been able to greatly enhance the performance of the hybridization kits through optimized control systems and BMSs. Interestingly, as per KPIT's own admission, it is this intellectual property (IP) that is being sought by the international OEMs, perhaps for use in their own hybrid solutions.

From a policy enablement perspective, the only noticeable support so far has been in the facilitation of testing routines at the ARAI. Active financial or R&D support for encouraging the development or deployment of hybridization kits has been lacking. Although the NEMMP 2013 recognizes hybrid kits as an active hybridization pathway and proposes capital subsidy as well as R&D support for them, there is still no policy support for this particular technology path.

Because of the lack of incentives for the Indian consumer, KPIT is planning to offer batteries (which constitute a large fraction of the overall cost of the solution) on lease to make the product more affordable, mitigating the high maintenance risk. The details of the programme and the partners are yet to be finalized and as such the new business model is still not clear. The firm also realizes that the usage data gathered through the telematics provision on the vehicle is crucial both from the point of view of better service provision and product improvement. An on-board GPS-enabled system transmits a number of performance metrics to the KPIT data centre for further analysis.

5.2 TVS Qube

The first Indian EV wave – cheap electric bikes, scooters and cycles imported from China – started in 2007–2008. These vehicles sold well initially, with the promise of much lower

16 See: http://www.malaysia-motoring-news.com/?p=901.

running costs as well as easy use. However, within a year the bubble burst. The main reason for this was that the pioneer distributors failed to set up a post-sale service infrastructure. This factor took away the “credibility” of electric bikes, scooters and cycles in India. The high replacement cost of batteries also hampered new sales. The initial debacle was such that even established two-wheeler producers in India like TVS were forced to discontinue the production and sales of their pure EV products (which themselves depended heavily on Chinese components).

During 2009–2012, TVS – one of India’s largest two-wheeler producers – developed a plug-in hybrid two-wheeler based on Li-ion batteries with significantly improved hybrid mode efficiency. This is the first hybrid two-wheeler in the world expected to retail at only a USD100 price premium over a similar ICE powered vehicle. A small (0.25–1 KWh) Li-ion battery provides a short pure electric range (~10 kms.) and thereafter uses the battery to support the hybrid mode (with stop-start, regenerative braking etc.). The advantage of using a small battery lies in the low additional cost and the lack of a recharging requirement.

India is an attractive market for two-wheeler EVs because of the large two-wheeler market – annual sales (including motorbikes and scooters) exceed 13 million units – and two-wheeler buyers are very price conscious; in addition, the price of petrol has been increasing rapidly in the recent years. As battery operated EVs face the problems of electricity shortages, infrastructural issues and high battery costs, hybrid vehicles that provide better fuel efficiencies and lower running costs with only a marginal increase in purchasing price offer an attractive alternative.

TVS has spent approximately USD 10 million per annum on hybrid vehicle development research, a major part of which is devoted to the design and development of electric motors, control systems and battery testing. The overall programme has resulted in over 14 patents, primarily in the control systems and BMS areas. With the realization that battery technology expertise in the firm and even in the country was lagging behind, TVS decided to procure battery cells off the shelf from suppliers in Korea and Japan. While battery cells from these countries were more expensive than those supplied by Chinese firms, the latter were found to be unsuitable because of inconsistent quality.

The development of the electric drivetrain (including electric motors) was done through collaborative R&D with Lucas TVS, a TVS group company that specializes in electric motors manufacturing. Having string mechanical systems design expertise, TVS undertook the chassis development work entirely in-house. Expanding the existing relationships with the electric component manufacturers for the ICE products, TVS undertook joint R&D work with these suppliers for developing electrical components and control systems for the hybrid vehicle. Besides these linkages, the in-house team has also collaborated with a number of foreign suppliers and small firms on specific technology issues.

While the Qube is undergoing market deployment trials, the commercial launch has been postponed from 2013 to 2014. Meanwhile, even though no investments have been made so far in dedicated manufacturing capacities, our interviewees indicated that with minor changes the existing two-wheeler assembly lines could be modified to manufacture the Qube as well.

Although this hybrid solution at present is only targeting the Indian market, there are similar developing country markets where efficiency enhancements are valued but where pure battery EVs are not yet in demand. With TVS already exporting ICE two-wheelers to over 50 countries, the firm intends to follow up the launch of Qube in India with an international launch of the hybrid vehicle. In the near future, as the hybrid technology in two-wheelers gains acceptance and battery costs decrease, TVS (and other Indian players) may introduce hybridization in other products, which in the case of TVS includes three-wheelers.

Underlying currents

The Indian two-wheeler industry has evolved considerably over the past decade, having invested significantly in knowledge sourcing and generation through JVs, acquisitions, partnerships and in-house R&D. Coupled with stringent regulatory provisions, price sensitive consumers and the highly competitive market, this means that the domestic ICE two-wheelers are among the most efficient worldwide.[17] The innovation and product development capability is expected to provide a springboard to chassis, mechanical and drivetrain related technologies.

At present, two major trajectories (pure EVs and hybrids) are present worldwide, which again are divided in high and low performance segments. Although the low-performance pure EV trajectory is quite well established in China, high performance pure battery and hybrid vehicles are only present in niche markets in the developed countries. Qube follows the low performance and low cost hybrid trajectory. TVS has collaborated with domestic power electronics and IT firms, and made great in-house efforts, to develop control systems and BMS for the hybrid vehicles.

5.3 Mahindra REVA NXR (E20[18])

REVA was one of the first pure EV to be manufactured in India. Since 2001, almost 5,000 vehicles have been sold in India and abroad (primarily the UK). Despite the head start for the company, the vehicle technology did not develop much during the next eight to nine years and the REVA of 2010 bore a close resemblance to the early versions of the car, both aesthetically as well as technologically. A major drawback of the vehicle apart from its small size was the lead acid battery technology that severely limited the performance and the driving range of the vehicle. During 2008, the firm briefly developed a close relationship with General Motors and at one point REVA's technology was adapted to produce EV versions of GM's small cars in India, albeit only for demonstration purposes. Following this, at the 2009 Frankfurt motor show, the REVA NXR – with improved chassis design, Li-ion batteries, more efficient motors as well as a larger body was introduced. Over the next three years, as the relationship with GM soured and Mahindra & Mahindra acquired a majority stake in REVA in late 2010, events that were perhaps not unrelated, the launch of REVA NXR/E2O was delayed on several occasions. The product was finally launched in March 2013, at a price of approx. USD 15,000 without a national capital subsidy framework, although states like Delhi provide a 20% purchase subsidy.

17 According to the IEA's technology roadmap on fuel economy of road vehicles, vehicles in India (both two-wheeler and four-wheeler) have the lowest fuel consumption for every 100 k. travelled within the reported countries.

18 During 2009–2012, the new REVA vehicle was named as REVA NXR but a rechristening in late 2012 changed the name to REVA E2O.

The delays in the commercial launch of the REVA E20 were a result of the price increase caused by the large Li-ion batteries, adding almost 50% to the vehicle cost over a comparable ICE vehicle – see Figure 1). As a result, the success of the product still depends on the introduction of a proper enabling policy framework, as discussed before.

Mahindra REVA is assembling the E20 at its new factory in Bangalore, with a capacity to produce 30,000 cars per year. Unlike the company's poorly selling, micro-sized initial products, the E20 is roomier, has a 100 kilometer range and a plastic, lightweight body. Several innovative features, such a solar charger, fast charging capabilities as well as a telematics based monitoring and car management system, have also been developed for the car (see Box 3).

In terms of the body and chassis design, REVA uses the space frame chassis manufacturing discussed in the previous section. Further, REVA has collaborated with composite manufacturers abroad to custom manufacture their body panels to ensure low weigh without compromising on robustness. The motors and motor controllers were optimized using the in-house expertise of the Mahindra group.

Figure 11: Comparing REVA E2O with the Nissan Leaf on performance parameters

Parameter	REVA E2O	Nissan Leaf (2012 model)
		
Range (Kms)	100	160
Top Speed (Kmph)	100	150
Battery Size (KWh)	10	24
Tentative Battery Cost in USD (@USD 500/KWh)	5000	12000
Charging Time (Hours)	6	8
Unsubsidized Price in USD	15000	35430

All figures are company quoted and not EPA or any certification agency tested.

Source: Company press releases and website

A significant fraction of the R&D expenditure at REVA has gone into developing the battery management system (BMS) for the E2O, reflecting a strong electronics and IT capability in the firm. The core IP of over 30 patents in the BMS, extending from battery pack development to the thermal and electrical management of the pack, also incorporates insights from over 220 million k. real life usage data obtained from the on-road REVA fleet. The battery cells have been imported from Chinese suppliers and optimized for use in the battery pack for the E2O. The telematics and communication technologies have been integrated into the car to provide feature sets available only in high-end cars, improving the market appeal of the vehicle. The development of the connectivity solutions as well as the linked analytics framework has been done in-house.

The REVA E2O has been positioned as an intra-city car (although an intercity version for the EU is also under development) with a limited driving range, primarily intended as the second car for a family – a segment that accounts for almost 40% of new car sales in India. At present, Mahindra is working on increasing the number of charging points in Indian cities. The car maker is already in talks with various state institutions, shopping malls, power distribution companies and others to add 300 to 500 charging facilities to the existing 100 in the country. That said, the niche 'intra-city/ second family car' positioning of the vehicle may not require an extensive public recharge infrastructure, with home and office recharging being touted as sufficient for the REVA E2O users.

Underlying currents

As Indian small car buyers are very sensitive to the running cost of their vehicles, the recent deregulation and subsequent rise of petrol prices in the country has caused the demand for cars using petrol to stall. Vehicles using other power sources, providing more affordable mobility can benefit from this development. The present struggle of the REVA cars derives from both financial as well as performance and reliability issues. Given the lack of capital subsidies the financial issue will remain for the moment, but Mahindra REVA has tried to address the latter through the REVA E2O.

The development of the REVA E2O is instructive in multiple ways. While on the one hand, some technology systems such as the BMS and telematics have been developed in-house, the firm initially had to rely heavily on foreign suppliers for electric drivetrains, and production was low. Following the acquisition by the Mahindra group, the firm gained access to manufacturing scale-up expertise and benefitted from the superior technological capabilities in sub-systems shared with ICE vehicles. In the case of REVA, apart from integration within a larger automobile conglomerate, there seems to be a shift in terms of the knowledge linkages from mostly foreign suppliers and technology partners in the first half of the last decade to knowledge linkages within the country in the form of domestic suppliers. The vehicle still relies on imported components such as tyre pressure monitoring systems from Schrader International, a US-based supplier.[19] Interestingly, despite the acquisition by Mahindra, REVA is still free to license its BMS related IP to other firms abroad (although it is not clear if any firm is indeed acquiring these licenses).

During the past decade, REVA has received various forms of policy support for its EV ranging from capital subsidies to soft loans for product development to testing facilitation. More recently, with the NEMMP recommendations placing emphasis on encouraging R&D in and promoting deployment of pure battery EVs, there is indication of renewed policy support for the REVA E2O and other future pure battery EVs. Interestingly, the policy strategy of the Indian government for the pure battery EVs mirrors the REVA deployment strategy in that neither focuses (or relies) much on public charging.

19 See: http://www.schraderinternational.com/News-and-Press-Releases/Mahindra?sc_lang=en-US-NA.

5.4 The discussion so far

This paper began with defining historical, structural and technological character of the EV sector in section 2. In section 3, the paper presented the broad context within which the Indian EV trajectory is embedded, highlighting the factor conditions, demand conditions, policies and other externalities shaping (and likely to shape) the EV sector. Following this, section 4 delved on the characterising elements of the trajectory, with the present section highlighting these using specific, representative cases. The final section below presents the key findings of this exercise with an aim to summarise the paper across the principal dimensions as highlighted during the discussion so far.

6 Discussion of India's unfolding EV trajectory

A number of technological, financial and socio-political factors are shaping the global EV trajectory. Within this trajectory differences in technological prowess, domestic firm strategies, policy imperatives and domestic markets are lending a unique flavour to different national trajectories. The case of India, as elaborated in the preceding sections, highlights the role played by diverse firm strategies against a backdrop of distinctive market conditions, with little long-term policy guidance. In the near future, the evolution of these factors (embedded as they are in the global context) would determine the shape that the Indian EV trajectory assumes. This section summarises the evolution of the EV trajectory in India across various facets that, going forward, would shape the trajectory.

Hybrid or pure EV?

The electric vehicles trajectory in India, while on the surface still in its infant atage, benefits from the decade-long changes in the Indian automobile industry. As the discussion in the previous sections illustrates, EV-focused solutions are materializing in the industry despite the lack of an adequate framework as in China, France or Germany. Still, the expectation of a policy in the near future has helped to motivate the industry to take up EV-focused R&D, as did competition in the domestic market and the global ambitions of the Indian players. As one looks closer at the emerging Indian EV trajectory, it is clear that a number of players are approaching the EV-PHEV-HEV continuum from the HEV direction (or the ICE direction). As the Revolo and TVS Qube cases demonstrate, and as reports of hybrid vehicle development at Mahindra and TATA confirm, major Indian players are at present investing in the hybridization of ICE engines. There are at least a couple of reasons for this. Hybrid technologies (such as regenerative braking, stop-start etc.) are seen to be on the ICE technology frontier in terms of achieving higher efficiencies. In the Indian market, with its running-cost sensitive buyers, developing competence within these technologies is a pragmatic strategy. It may turn out that with the decreasing battery prices and more research into hybrid technologies these technologies offer viable alternatives (or complements) to the present efficiency-enhancing technologies like turbo-boosters etc. Further, OEMs are reluctant to devote resources to the development of pure battery driven EVs, as the market is non-existent in the absence of subsidies and an enabling infrastructure. In the case of hybrids, the viability gap for the commercialization is much lower and more likely to close with technology advancements and battery price drops. Finally, for some mobility applications with large travel requirements, even present hybrid solutions make good commercial sense, with payback periods ranging from three to four years (based on deployment cases provided by KPIT Cummins).

Another sub-trajectory in the Indian EV story is represented by Mahindra's REVA development efforts. As the positioning and launch delays of the REVA E2O indicate, it is a challenge to deploy pure battery EVs in India without a major capital subsidy support. It appears that the obstacles to pure EV deployment are even higher in India. The high price, the financial challenges of setting up a public charging infrastructure as well as the incremental power demand on an already weak electricity grid make any serious pure EV deployment an uphill task. As a result, within this sub-trajectory, we have vehicles targeted at niche usage patterns in a second-car role; a real substitute for ICE vehicles is not in sight. Furthermore, the lack of public charging means that only home charging is unproblematic. This sub-trajectory is likely to play, as the stakeholders admit, a very minor part in the automobile industry in India. On the other hand, the development capabilities of the Indian OEMs in hybridization technologies, coupled with their lower reliance on battery and charging infrastructure, are likely to provide an impetus to the spread of hybrid technologies in the near future.

Global, local or glocal?

Based on the limited data on the global EV landscape, none of the players sees exports as a primary focus at present. However, it is interesting that almost all are confident about the chances of exporting either products or licensed IP in the near future. For instance, Mahindra considers the EU to be a potential market in the near future for the REVA E2O, while KPIT is already in negotiations with some global OEMs for licensing its IP around Revolo development. The primary focus however remains on domestic market sales as soon as an enabling policy framework is in place.

In terms of knowledge, there has been a transformation towards greater reliance on indigenous knowledge. REVA relied heavily on support from US-based firms for the development of its initial passenger vehicle models. Similarly, the first two-wheeler EVs were imported kits from China. This reliance has diminished greatly and the firms involved have built up capabilities to develop most product sub-systems either in-house or in collaboration with local suppliers, as the TVS Qube and Revolo cases show. However, a couple of sub-systems remain where there are knowledge linkages with foreign suppliers and firms. Electric motors require optimization of the various performance parameters, and while players like KPIT have developed competence in motor design, others like Mahindra REVA still rely on supplier expertise. There is no research and manufacturing capability in advanced battery technologies; India relies on foreign suppliers. In the case of battery cells, there is no significant activity in advanced battery chemistries in India. All the players rely on battery cells imported either from China (lower quality, lower price) or Japan and South Korea (higher quality, higher price). Interestingly, though, some Indian EV players like TATA have entered into basic battery chemistry research with US firms (A123 systems). From a technology sub-systems perspective, the Indian EV innovation system seems strong in control systems, BMS and telematics, with reasonable competence in electric drivetrains, chassis design and systems integration. The global OEMs as well as tier-1 suppliers in the Indian market don't do any R&D on EVs – understandably, due to their primary focus on other markets.

Network disruptions

The emergence of electromobility is expected to herald a shift in the balance of power and player profiles in the traditional automobile industry, due to the emergence of technologies and sub-systems hitherto not a part of the ICE supply chain. Globally, this shift could materialize in three broad ways: one, the emergence of new OEMs who specialize in EVs; two, a strengthening of the role of the existing suppliers, reflecting a change in the balance of power within the ICE innovation system; three, a role for players who are new to the automobile sector in the supply chain as manufacturers of products specific to EVs (such as battery makers). Of course, at the same time, the existing network of ICE OEMs and suppliers could gradually build up capabilities in the new technologies and sub-systems and extend their reach in the emerging electromobility sector. In the Indian case, as evidenced by the sectorial overview and the specific cases, all three categories of newcomers have materialized, albeit with a different influence and involvement in the respective technologies. For instance, EVs have given OEMs such as REVA, Electrotherm and Hero Electric an opportunity to enter the automobile/motorcycle sector. These players have been leading the pure BEV trajectory in India, in the absence of product launches from the traditional IC OEMs. It should be remembered, however, that two of these newcomers are subsidiaries of larger ICE category conglomerates (REVA – Mahindra; Hero Electric – Hero).

The Indian EV sector has also seen the role of suppliers such as KPIT Cummins and Bharat Forge increase. These now own significant IP in specific EV technologies (BMS and motors in this case) and are looking for OEM partners interesting in these technologies. For the Indian automobile sector, which has traditionally been ‘specification-driven’ by the OEMs, this is a unique phenomenon. The third category of new entrants in the supply chain has been limited to battery supplier firms from abroad. Their role in the Indian innovation system and in shaping the technology trajectory has been quite limited. Thus, the only major new entrants to the Indian EV innovation systems with a potential to change the trajectory have been the tier-1 suppliers.

As a result, the advent of an EV paradigm in the Indian transportation sector is likely to cause several network disruptions. While some suppliers (with ICE-only products) would struggle to find a role within the new paradigm, some can potentially have a greater role. Moreover, as players such as the oil and oil marketing companies, which are key stakeholders in the fossil fuel transportation economy are trying to position themselves in the EV sector through moves into charging infrastructure provision, it is still too early to say what the eventual ecosystem would look like.

Policy sculpting?

With the termination of the Alternate Fuel for Surface Transportation Programme (AFSTP) last year, there is at present virtually no policy framework for the EV sector; only limited state-level are subsidies available. The three cases showed that, apart from limited capital subsidies, no significant policy support was extended. The recommendations for national electromobility in the NEMMP document are yet to be adopted by the policymakers. Moreover, while the recommendations of the NEMMP include capital subsidies, directed R&D support as well as public charging infrastructure provision, the timelines for these support mechanisms differ. The capital subsidy support is expected to be available at the onset of the programme, with R&D support following soon and the creation of a charging infrastructure creation following later. Even in the R&D support recommendations there is a realization that, given the present domestic innovation capabilities in the various technology subsystems, the R&D needs of these areas would be different. For instance, while universities and national laboratories are to undertake basic research in battery technologies, support for improving the existing capabilities in drivetrains, control systems and power electronics is to be given to the industry. It is useful to note that the capital subsidy provisions appear to be skewed in favour of battery EVs, with a strong correspondence between battery size and capital subsidy. As a result, hybrid solutions attract lower subsidies than pure battery EVs. There does not seem to be any strategic policy choice for a particular technology type, although there is a focus on research within sub-systems that offer high value addition and can draw on existing innovation capabilities in India (e.g. power electronics, control systems, BMS etc.)

To conclude, the Indian EV case presents interesting insights into the dynamism of an eager industry, positioning itself for the future in Indian as well as global markets, while waiting for an enabling policy to start its deployment. The technology trajectory with its seeming preference for hybrid technologies is a manifestation of the present innovation capabilities, strategic outlook and risk appetite of the local players. The lack of interest of global OEMs is plausible given the Indian EV market and policy and their involvement in more lucrative markets elsewhere. Overall, the trajectory has developed towards greater local reliance for most technology sub-systems and is poised for increased activity – limited in the case of pure EVs and perhaps more extensive in the case of HEVs – as soon as the EV policy is implemented.

Bibliography

ACMA Reports: ACMA Annual Reports, (2011–12, 2009–10, and 2008–09), Automotive Components Manufacturer Association of India, New Delhi

Altenburg, T. (s.a.): From combustion engines to electric vehicles : implications for technological trajectories : case study Germany, Bonn: DIE (Discussion Paper), forthcoming

Altenburg, T. / S. Bhasin / D. Fischer (2012): Sustainability-oriented innovation in the automobile industry : advancing electromobility in China, France, Germany and India, in: *Innovation and Development* 2 (1), 67–85

Anderson, S. T. et al. (2011): Automobile fuel economy standards : impacts, efficiency, and alternatives, in: *Review of Environmental Economics and Policy* 5 (1), 89–108

Balcet G. / J. Ruet (2011): From joint ventures to national champions or global players? : alliances and technological catching-up in Chinese and Indian Automotive industries; online: http://revel.unice.fr /eriep/?id=3309

Business Standard (2012): Electric two wheeler sales affected due to withdrawal of incentive policy by MNRE, in: *Business Standard* 19 June 2012; online: http://www.business-standard.com/india/news/ electric-two-wheeler-sales-affected-due-to-withdrawalincentive-policy-by-mnre/477727/ (accessed 29 Nov. 2012)

CSE (Centre for Science and Environment) (2012): Fuel economy standards: getting the principles right, New Delhi

– (2009): CNG programme in India : the future challenges, New Delhi

DOE (U.S. Department of Energy) (2013): Federal tax credits for electric vehicles; online: http://www.fuel economy.gov/feg/taxevb.shtml (accessed 06 June 2013)

Dubash, N. K. (2013): The politics of climate change in India : narratives of equity and co-benefits; online: http://wires.wiley.com/WileyCDA/WiresArticle/wisId-WCC210.html (accessed 06 March 2014)

*IBEF (Indian Brand Equity Foundation) (*2008): Automotive market and opportunities : report, Gurgaon

IBEF (Indian Brand Equity Foundation) (2012): Engineering Design and Development: report, Gurgaon

ICRA (2012): Indian two wheeler industry (ticker note); online: http://icra.in/Files/ticker/Indian%202W% 20Industry.pdf (accessed 06 June 2013)

IEA (International Energy Agency) (2009): Transport, energy and CO_2 : moving toward sustainability, Paris

– (2010): World energy outlook 2010, Paris

– (2013): Global EV outlook : understanding the electric vehicle landscape to 2020, Paris

Fischer, D. et al. 2014, ## DIE Discussion Paper, Bonn: German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE)

HBL (Hindu Business Line) (2012): India's crude oil import bill jumps 40% to $140 bn in FY12, in: *Hindu Business Line* 13 June 2012; online: http://www.thehindubusinessline.com/: http://www.thehindu businessline.com/industry-and-economy/article3523827.ece (accessed 29 Nov. 2012)

McKinsey & Company 2012: Hensley, Russell, John Newman, and Matt Rogers. "Battery technology charges ahead." *McKinsey Quarterly* 3 (2012): 5–50.

Narayanan, B. G. / P. Vashisht (2008): Determinants of competitiveness of the Indian auto industry (ICRIER Working Paper 201); online: http://www.icrier.org/pdf/working%20paper%20201_final.pdf (accessed 06 March 2014)

NATCOM (2007): India : greenhouse gas emissions 2007, Dehli: Ministry of Environment and Forests of the Republic of India; online: http://moef.nic.in/downloads/public-information/Report_INCCA.pdf

Pradhan, J. P. / N. Singh (2008): Outward FDI and knowledge flows : a study of the Indian automotive sector, New Delhi: Institute for Studies in Industrial Development (ISID Working Paper 2008/2010)

Sagar, A. / P. Chandra (2004): Technological change in the Indian passenger car industry, Energy Technology Innovation Project, Kennedy School of Government, Harvard University (BCSIA Discussion Paper 2004–05); online: http://belfercenter.hks.harvard.edu/publication/2971/technological_ change_in_the_indian_passenger_car_industry.html (accessed 06 March 2014)

Schamp, E. (2014): The formation of a new technological trajectory of electric propulsion in the French automobile industry, DIE Discussion Paper, Bonn: DIE

SIAM Reports: Profile of the Automobile Industry in India, (2007–08, 2009–10, 2011–12), Society of Indian Automobile Manufacturers, New Delhi

Singh, S. K. (2006): Future mobility in India : implications for energy demand and CO2, in: *Transport Policy* 13 (5), 398–412

Singh, A. et al. (2008): Trends of greenhouse gas emissions from the road transport sector in India, in: *Science of the total environment* 390 (1), 124–131

The Hindu (2012a): Auto component industry growth to slow down to 8—10%, in: *The Hindu* 11 Oct. 2012; online: http://www.thehindu.com/business/Economy/auto-component-industry-growth-to-slow-down-to-810/article3987953.ece (accessed 05 May 2013)

– (2012b): Worst outage cripples north India, in: *The Hindu* 30 July 2012; online: http://www.thehindu.com: http://www.thehindu.com/news/national/article3702075.ece (accessed 29 Nov. 2012)

HT (Hindustan Times) (2012): India's oil import bill jumps 40% to $140 bn in FY12, in: *Hindustan Times* 13 June 2012; online: http://www.hindustantimes.com/business-news/WorldEconomy/India-s-oil-import-bill-jumps-40-to-140-bn-in-FY12/Article1-871109.aspx (accessed 04 June 2013)

Urban F. et al. (2012): The political economy of sustainability-oriented innovation systems in China, India and Europe – the case of wind energy and electric vehicles : presented at Globelics 2012, Hangzhou, China (Globelics12-P-0118)

VIBAT 2008: Breaking the trend visioning and back casting for transport in India & Delhi : scoping report, Delhi: Halcrow Group Ltd

Wonacott, P. (2009): India defies slump, powered by growth in poor rural states, in: *Wall Street Journal* 10 April 2009; online: http://online.wsj.com/news/articles/SB123931787215706747 (accessed 06 March 2014)

Shrink That Footprint (2013): Shades of green : electric cars' carbon emissions around the globe; online: http://shrinkthatfootprint.com/wp-content/uploads/2013/02/Shades-of-Green-Full-Report.pdf (accessed 29 Nov. 2013)

Annex

Annex 1: Stakeholders (discussed in detail in an earlier report on the key stakeholders in the Indian EV sector)

Actor	Local / provincial / state-level	National	Inter-national
Government	Government of Delhi Government of Maharashtra Government of Karnataka Transport Corporations Of Bangalore and Mumbai State Power Boards State Nodal Agencies State Pollution Control Boards	Department of Heavy Industries Ministry of New and Renewable Energy Ministry of Road Transport and Highways Ministry for Urban Development National Council/Board for Electric Mobility Ministry of Finance Ministry of Power (BEE) Department of Science and Technology Department of Industrial Policy and Promotion Central Pollution Control Board	
Business		Society of Indian Automobile Manufacturers Automotive Component Manufacturers of India Society of Manufacturers of Electric vehicles Mahindra Tata Motors Ashok Leyland Volvo Hero Electric TVS Motors Electrotherm KPIT Cummins Bosch Eaton India Curtis Exide Lohia Motors Bharat Heavy Electricals Limited KPIT Cummins	Toyota Nissan Honda Suzuki
Civil Society/ Research Institutes		Automotive Research Association of India International Centre for Automobile Technology Vehicle Research and Development Establishment IIT Delhi IIT Chennai IIT Bombay CSIR Labs National Association of the Blind TIFAC NMCC	

Annex 2: Relevant policies (presented in detail in an earlier report on the policy framework surrounding the Indian EV sector)

- National Council for Electric Mobility (NCEM)/National Board for Electric Mobility (NBEM)
- Strategic Plan for Department of Heavy Industry
- India’s Action Plan on Climate Change
- Fuel price deregulation
- National Auto Fuel Policy
- Land Acquisition Act
- Fuel Efficiency Labels for Passenger Cars
- Alternate Fuels for Surface Transportation Program (AFSTP)
- State-level Excise exemptions
- Automotive Mission Plan
- National Urban Transport Policy
- Incentives for R&D as provided in the National Auto Policy

Publications of the German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE)

Studies

80 *Pietschmann, Elena:* Forgotten or unpromising? The elusive phenomenon of under-aided countries, sectors and sub-national regions, 147 pp., Bonn 2014, ISBN 978-3-88985-587-9

79 *Vidican, Georgeta et al.:* Achieving inclusive competitiveness in the emerging solar energy sector in Morocco, 198 pp., Bonn 2013, ISBN 978-3-88985-586-2

78 *Reeg, Caroline:* Micro, small and medium enterprise upgrading in India: learning from success cases, 299 pp., Bonn 2013, ISBN 978-88985-585-5

[Price: EUR 10.00; books may be ordered from the DIE or through bookshops.]

Discussion Papers

14/2014 *Hausmann, Jeannine:* Turkey as a donor country and potential partner in triangular cooperation, 62 pp., ISBN 978-3-88985-633-3

13/2014 *Paulo, Sebastian:* International cooperation and development: a conceptual overview, 31 pp., Bonn 2014, ISBN 978-3-88985-632-6

12/2014 *Schamp, Eike W.:* The formation of a new technological trajectory of electric propulsion in the French automobile industry, 53 pp., Bonn 2014, ISBN 978-3-88985-599-2

11/2014 *Never, Babette:* Making energy efficiency pro-poor: insights from behavioural economics for policy design, 36 pp., Bonn 2014, ISBN 978-3-88985-631-9

10/2014 *Camacho, Luis A.:* Understanding regime support in new and old democracies: the role of performance and democratic experience, 30 pp., Bonn 2014, ISBN 978-3-88985-630-2

9/2014 *Ashoff, Guido / Stephan Klingebiel:* Transformation of a policy area: development policy is in a systemic crisis and faces the challenge of a more complex system environment, 32 pp., Bonn 2014, ISBN 978-3-88985-598-5

8/2014 *Banholzer, Lilli:* When do disarmament, demobilization and reintegration programmes succeed?, 43 pp., Bonn 2014, ISBN 978-3-88985-597-8

7/2014 *Yamineva, Yulia:* The governance of scientific assessment in the context of the Intergovernmental Panel on Climate Change: Lessons for international cooperation in science, technology and innovation, 24 pp., Bonn 2014, ISBN 978-3-88985-593-0

6/2014 *Pauw, Pieter et al.:* Different perspectives on differentiated responsibilities: a state-of-the-art review of the notion of common but differentiated responsibilities in international negotiations, 65 pp., Bonn 2014, ISBN 978-3-88985-596-1

[Price: EUR 6.00; publications may be ordered from the DIE or through bookshops.]

For a complete list of DIE publications:
http://www.die-gdi.de