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Electric Vehicles Scenarios and a Roadmap for India

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PROMOTING LOW CARBON TRANSPORT IN INDIA

Electric Vehicle Scenarios and a Roadmap for India

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CEPT UNIVERSITY
ज्ञानं विज्ञान सहितम्
Centre for Urban Equity

PROMOTING LOW CARBON TRANSPORT IN INDIA

Electric Vehicle Scenarios and a Roadmap for India

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Abbreviations

BAU	Business-As-Usual
BEV	Battery Electric Vehicle
BMS	Battery Management System
CNG	Compressed Natural Gas
CO_2e	Carbon dioxide-equivalent
E2W	Electric 2-Wheelers
E3W	Electric 3-Wheelers
E4W	Electric 4-Wheelers
ECM	Electric Cycles and Mopeds
EM	Electric Motorcycles
ES	Electric scooters
EV	Electric Vehicles
G2V	Grid to Vehicle
GHG	Greenhouse Gases
GoI	Government of India
Gt	Giga tonne
HEV	Hybrid Electric Vehicle
JnNURM	Jawaharlal Nehru National Urban Renewal Mission
LCMP	Low-carbon Comprehensive Mobility Plans
LCS	Low Carbon Society
Mtoe	Million tonnes Oil Equivalent
NAPCC	National Action Plan for Climate Change

NEMMP	National Electric Mobility Mission Plan
NMT	Non-motorized transport
OEM	Original Equipment Manufacturers
PHEV	Plug-in Hybrid Electric Vehicle
pkm	Passenger Kilometers
tkm	ton Kilometers
V2G	Vehicle to Grid
ZEV	Zero Emission Vehicles

Executive Summary

The National Electric Mobility Mission Plan 2020 was released by the Ministry of Heavy Industry and Public Enterprises, Government of India with a view to enhance national energy security, mitigate adverse environmental impacts (including CO_2) from road transport vehicles and boost domestic manufacturing capabilities for electric vehicles (GoI, 2012).

Urban transport planning in India has to address numerous challenges: deteriorating air quality, rising greenhouse gas emissions, and adverse rising energy security risks. There is increasing consensus among planners that a range of additional measures will be required, beyond the existing policies, to mitigate the adverse impacts of transport on these sustainability indicators. Electric vehicles (EVs) offer alternate mobility options that can help to redress these adverse impacts.

EVs so far have remained on the fringe. However, technology and battery advancements are making EVs more attractive to the consumer due to increasing convenience and affordability. EVs have already started to penetrate the market in several Indian cities. Given the established auto manufacturing industry in India, the expected growth in transport demand, and the recent interest in electric vehicles, India has the opportunity of creating domestic EV industry and emerging as a global leader in EV manufacturing market.

This report is an attempt to look at the present EV landscape, recent developments in EV markets and the emergent EV technology research. The report analyses future scenarios of passenger transport in India with a specific focus on the role of EVs. The scenarios span from 2010 to 2035 and are analysed using a bottom up energy system model: ANSWER MARKAL.

Key findings of the study

1. EV shares have increased globally and this has spurred numerous innovations in EV related technologies. For example, battery technologies are expected to undergo major transitions which will bring down costs and increase energy density.

2. Electric two and four wheelers with driving ranges and other characteristics comparable to conventional vehicles are available even today however costs and charging times are high.

3. Transport demand is expected to increase significantly in future. Two-wheelers will continue to remain the mode of choice in 2035. The share of four wheelers will increase significantly.

4. Electric two wheelers with low costs and limited driving range are suited for intra city driving since the trip lengths are shorter.

5. Large scale penetration of EVs will require both demand side incentives (e.g., tax incentives) and improved infrastructures.

6. Higher EV penetration will result in an increase in electricity demand however the demand is not very significant and does not require major capacity additions within the electricity sector and nor will it necessitate a major reordering of electricity supply.

7. Higher penetration of EVs provides benefits of energy security which become significant from 2025 onwards. This is due to a shift away from oil and a reduction in demand for final energy.

8. EVs also result in air quality benefits in the short term. In the low carbon scenario, where the EV penetration is highest, the emissions of PM 2.5 fall below half of the current levels by 2035.

9. EVs offer the opportunity to act as a distributed storage in the urban energy system which could help in better integration of intermittent renewables like wind and solar.

Finally, the substantial uptake and adoption of electric vehicles depends on global technological advances, awareness of citizens and support from national and local governments. The role of national governments is significant - in setting standards and regulations for charging infrastructures (devices and batteries), providing incentives for vehicles, investment into grids and charging infrastructures of batteries. The government can support research on innovative models for battery and vehicle technology, improving availability of charged batteries, recycling and reuse of batteries, using EVs for improving energy access, renewable integration, efficient pricing of electricity.

Local governments can facilitate EVs by a range of interventions including mandates and incentives that promote investments in charging infrastructure, developing local EV targets, setting stricter emission standards for vehicles, priority for EVs in parking and traffic, and facilitating public private partnerships.

Source: Authors

1. Introduction

Context

India is currently the fourth largest emitter of greenhouse gases (GHG) in the world. The transport sector accounts for 13% of India's energy related CO_2 emissions (INCCA, 2010). Opportunities exist to mitigate GHG emissions and make India's transport growth more sustainable and climate compatible by aligning development and climate change agendas. India's National Action Plan for Climate Change (NAPCC) recognizes that GHG emissions from transport can be reduced by adopting a sustainability approach through a combination of measures, such as increased use of public transport, higher penetration of bio-fuels, and enhanced energy efficiency of transport vehicles.

This document is produced as part of a larger research project on "Promoting Low Carbon Transport in India", an initiative of the United Nations Environment Programme (UNEP), hereafter referred to as the Low Carbon Transport (LCT) project. The key objectives of the LCT project are as follows:

a) Delineating an enabling environment for coordinating policies at the national level to achieve a sustainable transport system.

b) Enhancing the capacity of cities to improve mobility with lower CO_2 emissions.

The LCT project has been endorsed by the Ministry of Environment and Forests (MoEF), Government of India and is jointly implemented by the UNEP DTU Partnership, Denmark (UDP); Indian Institute of Technology, Delhi (IIT-D); Indian Institute of Management, Ahmedabad (IIMA); and CEPT University, Ahmedabad.

The Government of India recognizes the urgency to look at sustainable mobility solutions to reduce dependency on imported energy sources, reduce GHG emissions and mitigate adverse impacts from transportation. In order to mitigate these, a portfolio of interventions has been planned which includes fuel efficiency improvements, improving inspection and certification systems for reducing emissions from on-road vehicles, urban planning to reduce travel demand, improving mass transport, shift to alternative fuels and technologies including biofuels and electric vehicles, and overall system efficiency of infrastructure.

The National Electric Mobility Mission Plan (NEMMP 2020) was announced recently to incentivize use and production of electric vehicles (EVs) in India with a view to mitigate adverse environmental impacts of vehicles and to enhance energy security (GoI, 2012). In this context EVs are expected to play a significant role in low carbon transition of India.

EVs could have positive implications for national energy security, local air quality, GHG mitigation. In the long term, they could facilitate the increase in renewable energy share in the electricity sector. This report looks at the emergence of EVs in India, their different types and technologies, and analyses their role in India's long term transport scenarios.

Global Transport Transition

Transport sector, which is amongst the largest energy consuming sectors, is globally overly dependent on liquid fossil fuels. 93% of all the fuel used in transport sector was oil based in 2010. The sector is also a major source of GHG emissions and accounts for 22 % of total global energy related CO_2 emissions (IEA, 2011).

Transport sector energy demand and CO_2 emissions would increase at a rapid rate in the business as usual scenario (Clarke et. al., 2014) and therefore emission mitigation and reducing energy consumption from transport have been at the centre of various national and global energy and environmental policy debates in recent years. Concerns over climate change, energy security and air quality have resulted in significant changes in fuel and vehicle technologies. Electricity and low carbon fuels such as natural gas and biofuels are gradually replacing conventional fuels and technologies.

One of the key ways in which future emissions can be avoided is through the development and use of low carbon technologies (IPCC, 2007). In the context of decarbonising transport, Electric Vehicles (EVs) are one such option for CO_2 mitigation from light duty vehicle fleet. In order to meet the global 2° C target by 2050, three-fourths of all light duty vehicles sold in 2050 would have to be EVs (IEA, 2013). Mitigation costs for EVs could drop significantly in the future with lower battery costs and the decarbonisation of electricity, while offering the lowest emissions intensity among the light duty vehicle options (Sims et. al., 2014). Following concerns of national energy security and climate change, several countries have embarked upon ambitious policies to increase the share of alternate vehicles.

Scope

On 9 January 2013 the Prime Minister of India launched the National Electric Mobility Mission Plan (NEMMP) with a view to enhance national energy security, mitigate adverse environmental impacts (including CO_2) from road transport vehicles and boost domestic manufacturing capabilities for electric vehicles[1]. The Mission Plan envisions 6-7 million units of new vehicle sales of the full range of electric vehicles, along with resultant liquid fuel savings of 2.2 – 2.5 million tonnes (GoI, 2012).

In this report future scenarios of passenger transport in India are analysed with a specific focus on the role of EVs. The report is divided into five chapters. Chapter 1 is the introduction and sets the context and scope of the report. Chapter 2 discusses the global development of electric vehicles from a historical perspective and the emerging trends. Chapter 3 provides an overview of India's achievement and policy landscape for EVs. In Chapter 4, we analyse three different scenarios for EVs. The scenarios span from 2010 to 2035 and are analysed using the bottom up energy system ANSWER MARKAL model. The report concludes with a roadmap for EVs.

The report aims to shed light on the present EV landscape, recent developments in EV markets, ongoing research and touch upon the future of EV technology. The report makes a case for the role of electric vehicles as a sustainable mobility option for India. Although the focus of this report is on India, we have referred to EV related experiences of several countries as a source of reference.

1 http://pib.nic.in/newsite/erelease.aspx?relid=91444 Accessed November 17, 2014

Source: https://www.flickr.com/photos/jurvetson/7126943085

2. Electric Vehicles: Emergence and Relevance

'Electric Vehicles' are defined as vehicles which use an electric motor for propulsion (Simpson, 2011). The electricity used to run the motor could come through either transmission wires, as is the case with electric locomotives, metro trains, and trams or through a single or a series of connected batteries, as is the case in electric bikes and electric cars or it could be generated on board using a fuel cell. While acknowledging the former as a category of EVs, this report limits its scope to road transport vehicles that use either a battery or a fuel cell.

History of Electric Vehicles

The aforementioned types of EVs and the different technologies used in EVs have evolved over a period of time. The history of EVs in transportation goes back to 1880s when the first electric car was introduced in the German market. It was also around this time that other types of EVs such as electric suburban railways, electric trams and trolley buses were introduced. Electric vehicles gained popularity soon and more vehicles were introduced in other European and US markets. It was the same period when the first cars running on internal combustion engines (ICEs), the engines which drive almost all the cars running today, were introduced in the market. During the initial years, the interest in EVs surpassed that of vehicles running on ICEs, and EVs were extensively used during the World War I. However, issues related with charging infrastructure and charging time, and the need for charging infrastructure and competition from ICE vehicles affected the EV market adversely and several EV manufacturing companies went bankrupt after the stock market crash of 1929 (Hoyer, 2008).

EVs came in prominence again for a short period briefly after World War II. In the period from early 1950s to late 1980s, there were several attempts to popularize EVs. Along with electric cars, electric trams were among the earliest of electric vehicles to gain acceptance in cities. Even today, several cities in developed countries have well-functioning electric trams for public transportation. The trams began declining since 1960s in favour of diesel buses, which became the preferred mode for public transportation.

It was in the early 1990s, when concerns around vehicular emissions and global climate change started growing, that EVs regained the attention of manufacturers and policy makers. The state of California decided in the 1990s to set strict emission standards to deal with health problems caused by toxic air pollutants. The large size of the car market in California influenced the automobile industry not only in the US but also globally. Forced by the Californian zero emission vehicle (ZEV)[2] mandate, large car manufacturers showed increasing commitments to the battery electric vehicle (BEV) technology. Similarly, some demonstration projects in Europe were showing success. Since 2005, there has been a new impetus for electric mobility following concerns over climate change and energy security (Dijk et al., 2013). As a result of this stimulus, the global stock of electric cars has crossed 200,000 in 2013, although, it still represents a very small share of total passenger cars (ICCT, 2014; IEA, 2013). This renewed interest in

2 This includes vehicles that had zero tailpipe emissions - hydrogen fuel cell electric vehicles (FCEVs) and plug-in electric vehicles (PEVs), which in turn include both pure battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs).

EVs has also been referred to as the "third age" of EVs by the International Energy Agency (IEA) (IEA, 2013). This period is marked by large improvements in battery capacity and technology, and significant decline in costs of EVs and related components. Improvements in technology have also opened up the possibility of deploying EVs as both a generator as well as storage device, thereby using it for bidirectional power transfer (Guille & Gross, 2009).

Electric Vehicle Segments in Road Transport

Road EVs include a large range of vehicles from electric two-wheelers, three-wheelers (rickshaws), cars and electric buses. In this report the term electric two-wheelers (E2Ws) is used for both electric bicycles, and electric scooters, while electric four-wheelers (E4Ws) is used for electric cars, E3W is used to refer to electric 3-wheelers (including E-rickshaws), and E bus to refer to electric buses. In addition, plug-in electric vehicles can be classified into two types: battery electric vehicles (BEVs), and plug-in hybrid electric vehicles (PHEVs). BEVs have an electric motor in place of combustion engine and use electricity from the grid stored in batteries. Plug-in hybrid electric vehicles (PHEV) use batteries to power an electric motor and liquid fuel such as gasoline or diesel to power an internal combustion engine or other propulsion source (US DoE, 2014).

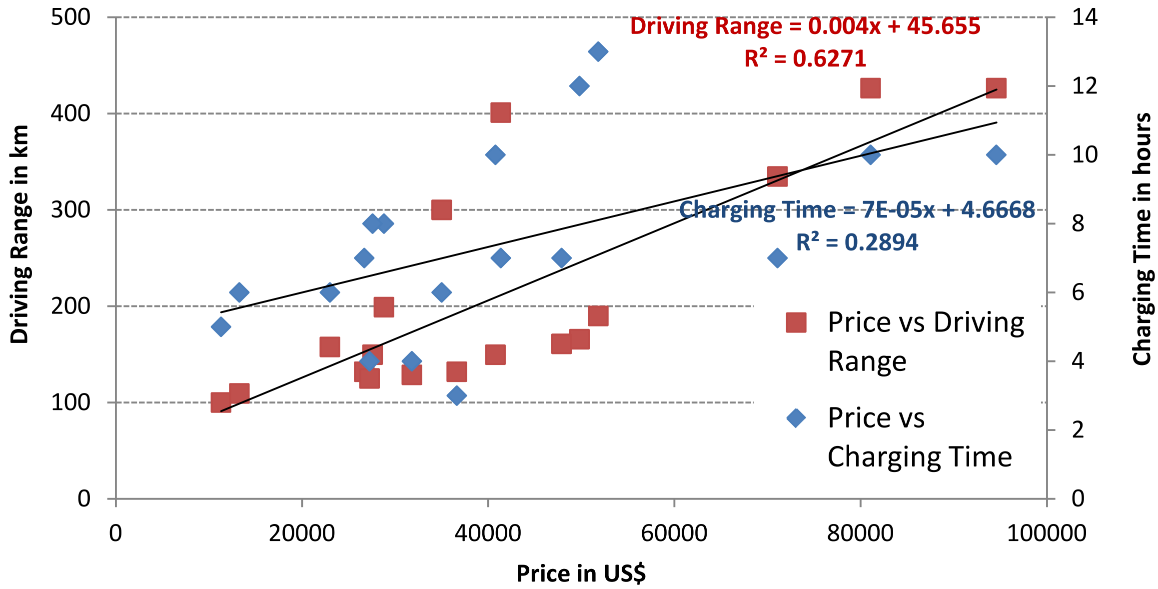
EVs can go beyond the above mentioned technology based classification[3], and can be classified on the basis of their attributes such as i) charging time, ii) driving range, and iii) the maximum load it can carry. Of these attributes, charging time of batteries (i.e. the time required to fully charge the battery) and driving range (i.e. the maximum distance an EV can run when fully charged) are perhaps the two most important characteristics of an electric vehicle of concern to the consumer. Charging time depends on the input power characteristics (i.e. input voltage and current), battery type, and battery capacity.

Advancements in electric vehicle technologies have led to expansion in the range of EVs available in the market. These include EVs primarily meant for intra-city (short distance travel) to those which can be used for inter-city transport (long distance travel). The driving range of EVs could be as low as 20 km per charge to as high as 400 km per charge. Similarly the top speed could go as high as 160 km/hour in case of E4Ws and some E2Ws. Figure 2.1 plots the two characteristics of E4W, charging time and driving range, with price for some popular E4Ws currently available in the Indian and global markets. A total of 18 models of E4Ws by 14 automobile manufacturers are included here. To allow for comparability across models, the data for the latest (i.e. 2013 or 2014, whichever was the latest) editions of models were used. The price of vehicles ranged from US$ 11,300 to US$ 94,570.

While most E4W have driving range less than 300 km, there are some E4W with range of over 300 km. Similarly the charging time is typically less than 8 hours, but for some vehicles the charging time tends to be higher. In general, E4Ws display a weak positive correlation between driving range with price of vehicles. Similarly there is a very weak positive correlation between price of vehicles and charging time. This is due to two opposite trends related to battery quality and motor size: higher price vehicles have relatively larger battery sizes but also better battery designs.

3 This technology based classification is not relevant to the end user who is more interested to see the EV as an option which enhances his utility

Figure 2.1: Driving Range, Charging Time, and Price of E4Ws for Indian and Global Models



Data Source: 18 commercially available models of EV

There are three types of E2Ws based on nature of technology: a) electrical cycles and mopeds (ECM), b) electrical scooters (ES), and c) electrical motorcycles (EM).They vary with regard to top speed, price, and pay load capacity. A review of 14 E2Ws manufactured was undertaken to understand the variation in the offerings. In all a total of 62 models were identified. A categorisation of the three categories on the basis of top speed and pay load capacity is provided in Table 2.1.

Table 2.1: Classification Criteria for E2Ws

Vehicle Type	Maximum Payload (kg)	Top Speed (km/hour)
ECM	mostly less than 80	less than 75
ES	more than 80	between 25 and 75
EM	more than 150	more than 75

Figure 2.2: Driving Range, Charging Time, and Price for Electric Cycles and Mopeds (ECMs)

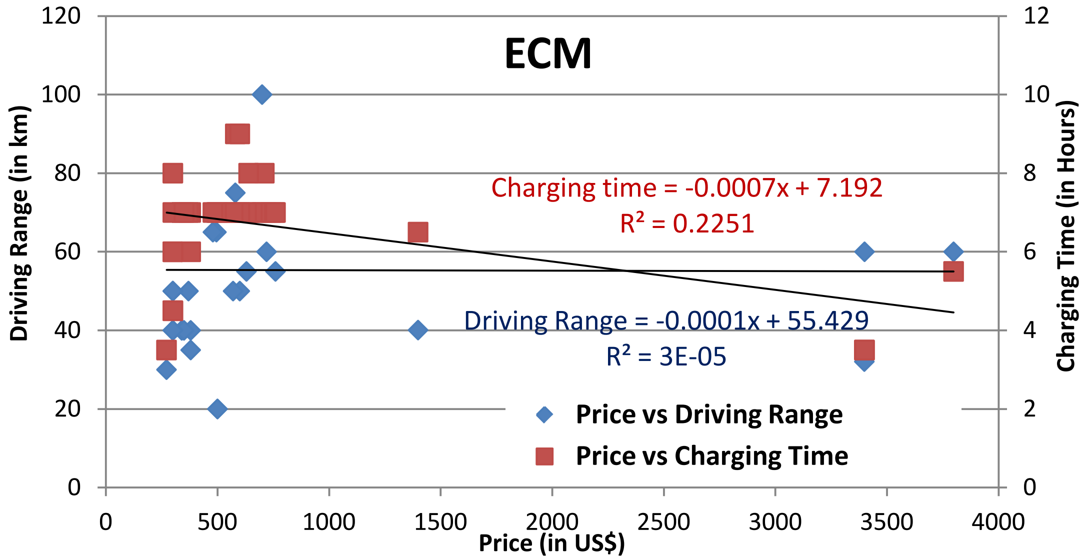


Figure 2.3: Driving Range, Charging Time, and Price for Electric Scooters (ES)

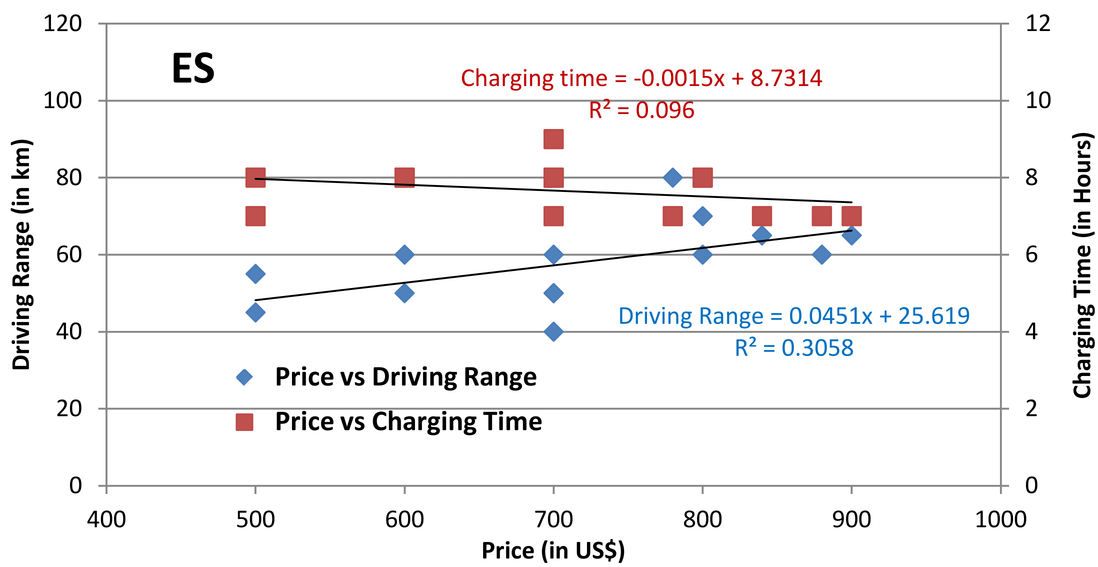
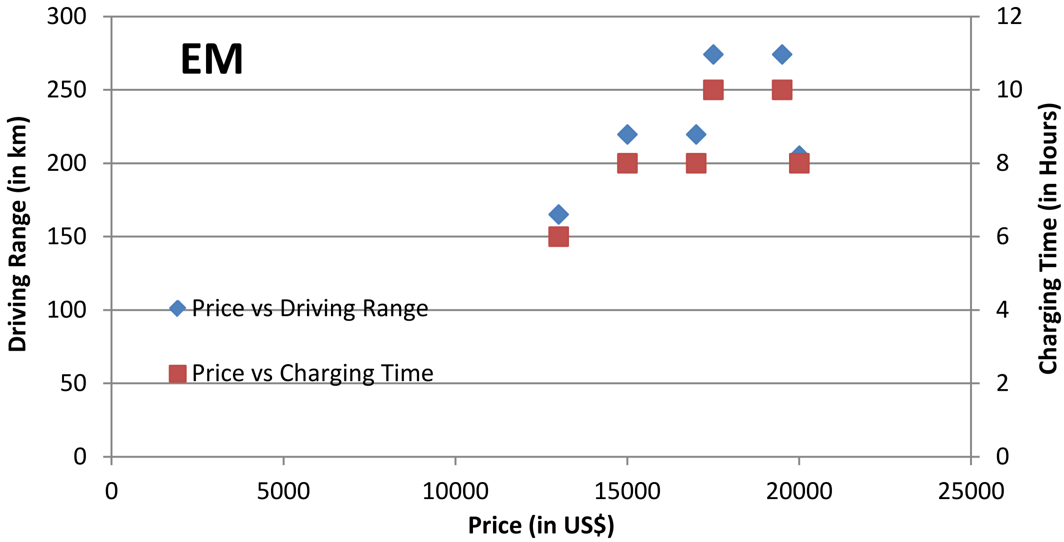


Figure 2.4: Driving Range, Charging Time, and Price for Electric Motorcycles (EM)



It can be observed from the figures 2.2 to 2.4 that charging time and driving range differs with type of E2Ws. Driving range does not increase much with price for ECM and ES and most ECM and ES have similar driving range. Meanwhile in the case of EM, there is a weak positive correlation and driving range in general increases with price. Similarly, the relationship between price and charging time is different for the three categories. While in case of ECM and ES, there is wide variation in charging time for vehicles in similar price bands. In case of EM the charging time increases with price in general; however since data points are limited, no correlation statistics are presented.

The three subtypes of E2Ws exhibit different ranges of charging time, with ECM having lower values on an average. Typically, charging time for ECM and ES is between 2 hours to 4 hours and with price they exhibit a weak and negative correlation. The driving range for most E2Ws ranges from 50 to 100 km, though there are some electric motorcycles with a driving range in excess of 200km. In case of E4Ws, there is a slightly larger variation as far as driving range is concerned. While there are some E4W with range as short as 100 km, there are also some models with a range in excess of 300 km.

The analysis shows that a wide variation in driving range and charging time exists today with current technologies. The major concerns regarding EVs today is their driving range and time required for charging. However, electric vehicle technologies have advanced significantly and EVs with driving range comparable to conventional ICE vehicles are available in the market albeit at a higher price. Moreover, the charging time for EVs can be below two hours if supported by dedicated infrastructure such as

E4W with driving range comparable to conventional ICE vehicles are available in the current market however the costs and charging time are quite high.

E2W such as electric cycles and electric scooters are mainly suited for intra city travels due to limitations of driving range

high power charging stations. These have been installed in several countries which have a relatively large market for EVs such as China, UK, USA, and Germany. Finally, with technology improvements and growth in the EV markets, vehicles with high driving ranges and lower charging time are likely to be available at a much reduced price. These developments can potentially further drive up EV sales in future.

Market Information

Recognizing the growing demand for cleaner vehicles, several automobile manufacturers are working proactively on vehicle and battery innovations to stay competitive in the emerging markets. More recently, there has been a growing interest in looking at hybrid electric vehicles as a transition technology, especially in developing country markets, to bridge the technology gap (UNEP, 2009). Modern electric vehicles have undergone significant improvements and in the case of E4Ws, almost every major global car manufacturer has launched a fully electric or hybrid model in recent years. In the near future, several innovations are expected to change the EV landscape. These will include vehicles with state of the art technology with high performance batteries that optimize efficiency. Though current sales have not yet met the automakers' expectations, the market is expanding steadily as fuel prices remain high and consumers are increasingly seeking alternatives. Encouraged by the expectation of expanding markets in the near future, manufacturers are now expecting to substantially reduce production costs[4]. Tesla Motors, a front runner in EV technology has shared its patents with competitors with the hope that this accelerates the development of electric cars in particular and electric vehicles in general across the industry.

Fig 2.5 shows the shares of different countries in the global E4W[5] market. The US and Japan have the largest stock of E4Ws. In terms of market share of EVs compared to all vehicles, Norway is the global leader with nearly 6% in 2013. Netherlands leads in the PHEV category followed by Sweden, Japan and Norway. In terms of share of E4Ws relative to all vehicles, 8 of the top ten countries are European countries (ABB, 2014). E4W markets in these countries have benefitted from national EV policies and targets, as well as a range of initiatives at the sub-national level. Various measures such as demand and supply side incentives (e.g. in the US and China) and building the charging infrastructure (e.g. in China, the UK, Japan, and Germany) have been adopted. The governor of California has recently announced an ambitious target of reaching 1.5 million zero emission vehicles (ZEVs) on California's roads by 2025. Currently, California takes up 40% of the total share number of plug-in electric vehicles in the USA. By 2015, automakers plan to launch fuel cell electric vehicles (FCEV) in the market[6].

Electric vehicle shares are increasing in a number of countries as an outcome of ambitious national targets, dedicated subsidies and investments in R&D.

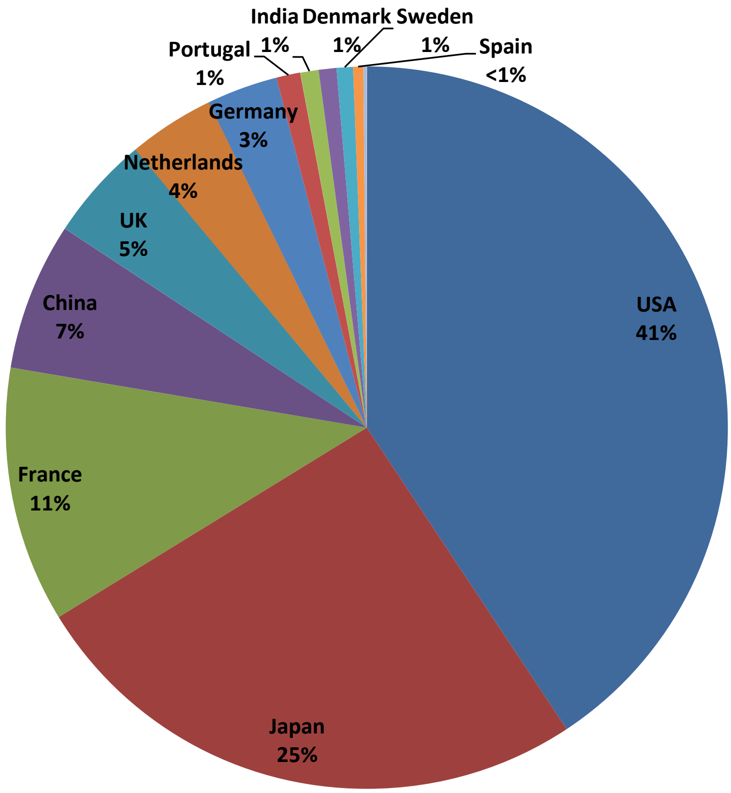
The global EV market is expected to grow significantly in the near future. Combined sales of E4Ws and HEVs will triple from current levels by 2020

4 http://www.teslamotors.com/blog/gigafactory Accessed November 13, 2014

5 This includes passenger car plug-in hybrid electric vehicles (PHEV), battery electric vehicles (BEV), and fuel cell electric vehicles (FCEVs)

6 According to the 2013 ZEV Action Plan. www.opr.ca.gov /docs/Governor's_Office_ZEV_Action_Plan_(02-13).pdf Accessed November 18, 2014

Figure 2.5: Share by country in Cumulative Registration/Stock of Electric Cars, 2012



(Source: IEA, 2013. Note: Figures indicate cumulative registration/stock of E4Ws)

Since the 1990s Chinese government has actively supported R&D on alternative vehicles and rolled out a comprehensive electric vehicle programme as part of China's five year plan (2001-05). The Chinese government has announced subsidies of up to 60,000 Chinese Yuan (about $9,700) to electric as well as hybrid electric vehicles. The country is the global leader in battery electric buses[7]. The city of Shenzhen, for instance, has promoted electric buses and taxis and plans to bring in 6000 electric buses in service by 2015[8]. Close to 30 million e-bikes were sold in the world in 2012, of which China alone accounted for 92%[9], and it is estimated that another 249 million will be sold in China by 2020[10]. Globally, combined sales of E4Ws and HEVs are likely to triple from current levels to 6.6 million units by 2020, making up 7% of the global light-duty vehicle market.

7 http://www.forbes.com/sites/greatspeculations/2014/05/30/china-poised-for-plug-in-electric-vehicle-volume-growth-going-forward/

8 http://www.iec.ch/etech/2013/etech_0413/tech-2.htm Accessed November 15, 2014

9 http://sustainabledevelopment.un.org/content/documents/3792fu2.pdf Accessed November 15, 2014

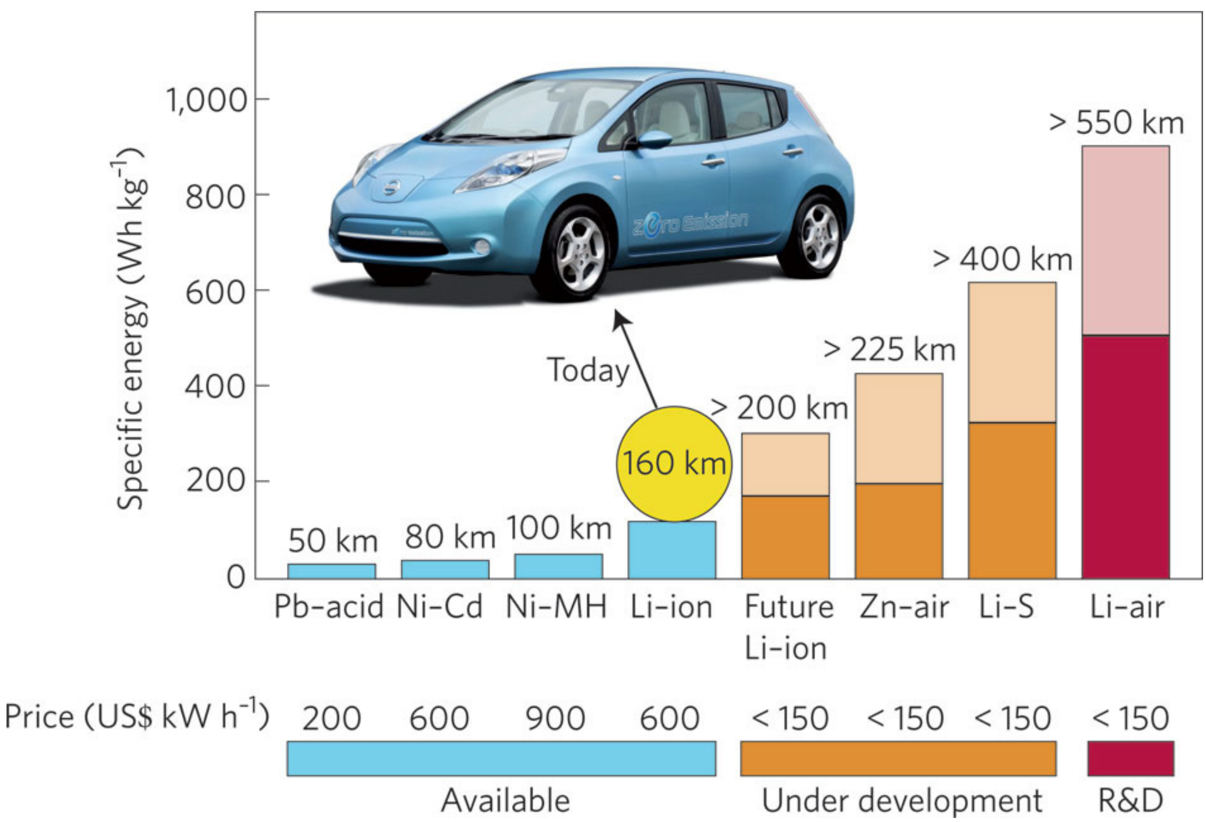
10 http://www.bloomberg.com/news/2014-05-15/carnage-on-china-roads-shows-dark-side-of-electric-bikes.html Accessed November 15, 2014

Battery Technologies and Costs

Battery is the most important component of an electric vehicle and typically constitutes up to about half of the vehicle cost and weight. The choice of batteries depends on the energy density, weight and costs. Electric cycles and low range mopeds have simple battery units while electric cars deploy a large number of batteries.

Traditionally, most electric vehicles have used lead-acid batteries due to their mature technology, easy availability, and low cost. However, since the 1990s battery technologies have evolved significantly and several new types of batteries have been developed (Zhang, 2012). More recently, batteries using combinations of lithium ion and its variations are gaining widespread acceptance due to better efficiency, reduced weight, lower charging time, better power output, longer lifetime, and reduced environmental implications from battery disposal. The following four types of batteries are commonly used today in EVs: 1) Lead Acid, 2) Nickel Cadmium (NiCd), 3) Nickel Metal Hydride (NiMH), and 4) Lithium-ion (Li-ion) . Lithium-ion batteries have higher specific energy relative to the other battery types. In the future, technology innovations with Li-ion and other battery technologies are expected to result in batteries with much higher specific energy and lower costs (Figure 2.6).

Figure 2.6: Battery Types: specific energy and prices



(Source: Bruce et. al., 2012)

The decrease in battery costs could be even higher since aside from the technological factors (battery technology, capacity (Wh), and energy density (Wh/kg), economies of scale brought about by increased demand of EVs may also play an important role.

Unsafe disposal of batteries can create adverse environmental implications. The end of life management and recycling of EV batteries in an environmentally safe manner will have to be dealt with through effective environmental policies and enforcement. Several countries have established policies and regulations aimed at reducing the environmental damage while ensuring the competitiveness of the automobile sector. For example, in the United States, the Department of Energy has granted $9.5 million to a recycling company to build a specialized recycling plant[11].

With improvements in battery technologies, battery costs have come down over time and are expected to drop further as the markets for electric vehicle and other allied markets expand in the near future.

With increasing use of EVs, governments will need to bring in mechanisms for end of life management and environmentally safe recycling of EV batteries.

The average cost of a battery pack has dropped from around $ 1000/kWh in 2010 to $ 600/kWh in 2014 and is expected to go down further to $ 150/kWh by 2030 (Bloomberg New Energy Finance, 2013). To support the national commitment to building electric vehicles and most of their components in the United States, the federal government has invested $2.4 billion in electric battery production facilities and nearly $80 million a year for research and development on electric batteries (CRS, 2013).

Infrastructure

The deployment and scaling up of EVs in urban areas greatly depends on the quality and access of charging infrastructure, and facilitation of a supply chain for charged batteries. Charging infrastructure includes low speed charging stations in homes and workplaces as well as fast charging points located in public areas including shopping malls and mass transit stations. Globally, several city governments have introduced plans and policies to improve EV infrastructure (Appendix A). The case of Amsterdam is a good example illustrating how public charging infrastructure in combination with policy measures can play a positive role in stimulating electric mobility in a city context (van der Hoed, 2013). The city currently has over 400 charging stations. This growth in number of charging stations has encouraged the use of charging infrastructure in terms of number of sessions and charging time. Other initiatives that may help scale up EV in cities include local plans for electric vehicles, subsidies, dedicated parking and related incentives, use of information technology (IT) to locate charging stations, collaboration with private companies, as well as public car share and lease.

11 http://www.energy.gov/nepa/ea-1722-toxco-inc-electric-drive-vehicle-battery-and-component-manufacturing-initiative Accessed November 16, 2014

In the future, charging infrastructure will be an important component for scaling up EV use in urban areas.

Local governments can facilitate EVs by a range of interventions including investing in infrastructure, integrating electric mobility in urban development guidelines, developing local EV targets, integration with IT platforms and facilitating public private partnerships.

Several cities in China have initiated extensive infrastructure upgrades for electric vehicle charging. Recently, the municipal government of Beijing announced plans to build 10,000 charging points for electric cars in Beijing. These will include both public and private charging infrastructure that will be installed in airports and train stations, public parking lots, parking lots of malls and supermarkets, highway rest areas, electric car stores and gas stations[12]. Building codes in China require new buildings to provide dedicated charging points in basement parking. Similarly, innovative business models are emerging in India, where EVs can be rented or batteries exchanged when the vehicle has run out of charge. Widespread adoption of EVs will also require creation and upgrade of infrastructure which can offer a significant business opportunity to private investors. Car companies are also looking at ways to promote electric cars which include initiatives such as common infrastructure, and sharing costs for building recharging stations[13]. It is expected that more such business models will develop in the future with the expansion of EV market. Accessible charging infrastructure is an important factor that will influence increase of EVs in urban transport and consequently further their role in providing grid support in cities. The experience in Beijing shows that charging time management and battery swapping can mitigate grid imbalance and minimize the need for power capacity additions (Lu, 2012).

Barriers to EVs

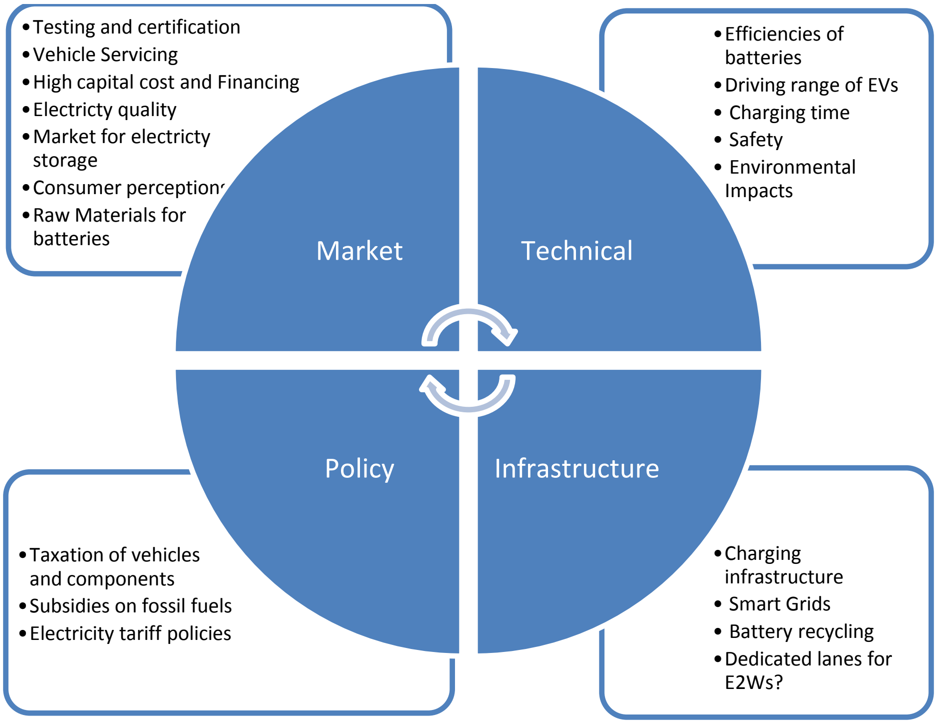
EVs are receiving increasing attention of policy makers and consumers due to a variety of factors including introduction of attractive EV models, and policies by national and local governments designed to promote EVs (IEA, 2010). However, scaling up EV penetration and realizing the potential requires dealing with technical, infrastructural, market, and policy related barriers (Fig 2.7)

Technical barriers involve issues related to efficiency of batteries, charging time, and driving range. One of the major barriers is the low specific energy density of most batteries used in EVs, especially lead acid batteries. To achieve reasonable driving ranges thus requires bulky batteries adding to the overall weight of EVs. To address this issue, battery manufacturers are working on advanced batteries with higher specific energy density, such as lithium ion and lithium sulphur battery which can reduce weight requirements of batteries in future, thereby leading to reductions in weight and possibly cost of EVs. Some other EV related concerns relate to the driving range and charging time of batteries. But as observed in the figures 2.1 to 2.5, even current technologies allow for EVs with high driving range and low charging time. As battery types and battery technologies improve, the concerns regarding driving range and charging time will get further reduced.

12 http://www.chinadaily.com.cn/business/motoring/2014-06/28/content_17621883.htm. Accessed 29 June 2014

13 http://www.themalaymailonline.com/drive/article/audi-draws-up-plans-for-range-of-electric-cars-sources#sthash.M7iVylOE.dpuf. Accessed June 25, 2014

Figure 2.7: Barriers to Electric Vehicles



Market and infrastructural barriers largely relate to lack of dedicated lanes for EVs, lack of charging infrastructure, and absence of business models to cater to specific needs of EVs. Dedicated lanes for EVs, particularly slow moving E2Ws or having a separate lane for cycles and ECM may be required to facilitate movement on Indian roads. Similarly, charging stations or battery swapping points should be available at commercial locations to ease concerns on charging options. Business models whereby EVs can be rented or where discharged batteries can be swapped with fully charged batteries at dedicated points may help expand the market for EVs in India. But as is the case with technical challenges, options exist even today to address some of these market and infrastructural challenges. Solutions to lack of charging infrastructure could include setting up charging points in basements of buildings and in parking garages as is being done in many other countries like China. Similarly EVs rental business models can help consumers experience EVs first hand and build consumer confidence. Such models can reduce upfront investment required by consumers and also help in increasing consumer confidence in EVs.

Policy related challenges include choosing and instituting policy instruments to promote EVs, setting up infrastructure, incentivize automobile manufacturers to produce EVs, and induce consumers to switch to EVs. In many ways, the challenges mimic the classical chicken and egg dilemma. Should the infrastructure be ready before penetration of EVs could go up? Or should the penetration of EVs reach a 'tipping point' before the required infrastructure is rolled out? The dilemma confronts policymakers, automobile manufacturers and the related businesses. The policymakers have to decide when to implement the

Deployment of EVs in large numbers is hindered by a variety of barriers. Scaling up EV penetration and realizing their full potential would therefore require addressing these barriers.

Solutions to address many barriers exist now, while solutions for some others are at different stages of development. Instituting policies is vital to effectuate these solutions.

policy roadmap in light of the numerous benefits EVs can provide. The automobile firms need to assess benefits and risks of being an early or a late mover into the EVs market. Firms may also decide to hedge their risk by investing in more than one emerging technology. Increasingly governments are supporting R&D in battery and vehicle innovations and providing a number of incentives to boost production and sales of EVs. National policies such as NEMMP of India can also help act as a lever to encourage the uptake of EVs.

There are public perceptions regarding utility, safety, driving range and costs comparable to conventionally powered vehicles. Understanding and addressing public perceptions will be necessary for policy makers and business to facilitate greater acceptance and shift towards EVs. Many of these concerns arise due to information asymmetry between the manufacturers and the consumers and can be dispelled by technological advancements and by deploying innovative marketing tools.

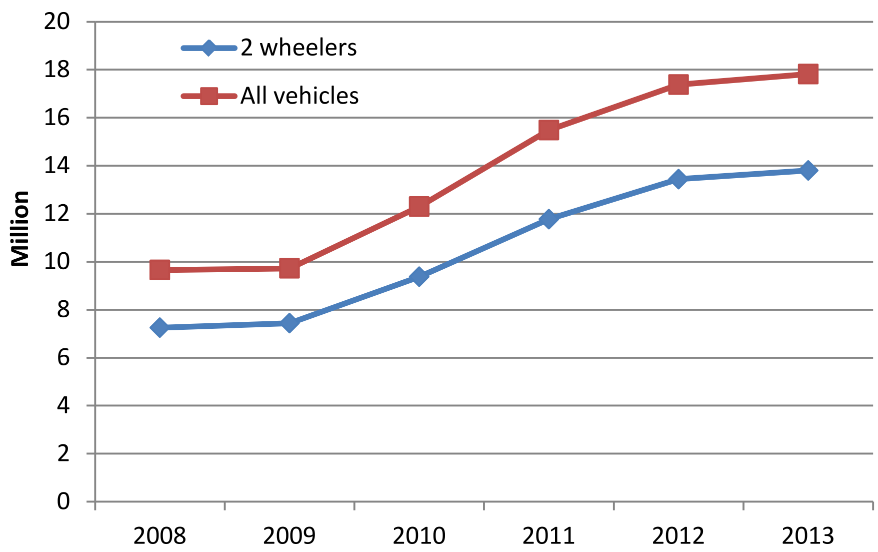
Source: Authors

3. Role of EVs in Urban Transport in India

Overview of India's Transport Sector

Urban transport in India is dominated by road transport and is one of the fastest growing sectors in the Indian economy. Two-wheelers dominate the sector accounting for 75% of total vehicles sold in the country (Figure 3.1).

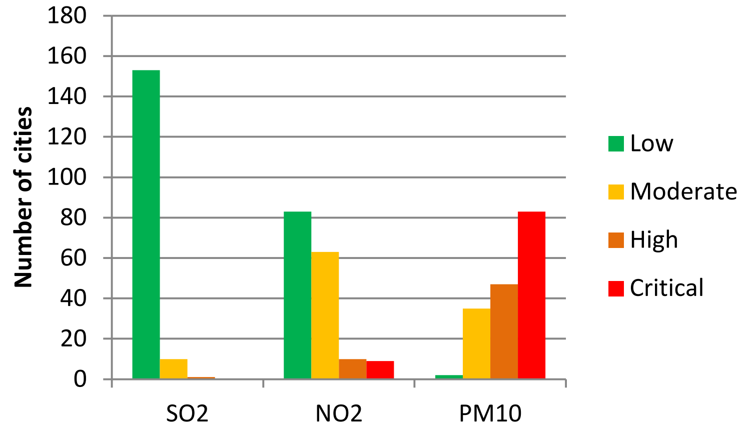
Figure 3.1: Domestic Automobile Sales Trends in India



Source: SIAM, 2014

These growing numbers of vehicles present local challenges of congestion and deteriorating air quality. In the past two decades, local air pollutant emissions from the transport sector have increased leading to severe air quality problems in a large number of Indian cities. A number of Indian cities are faced with poor air quality, especially with respect to levels of particulate matter and NOx. A recent assessment by the Central Pollution Control Board showed that over 75% of the cities surveyed had very high or critical levels of PM_{10}. Fifty percent of these cities had moderate to critical levels of NOx (Figure 3.2).

Figure 3.2: Air quality in cities



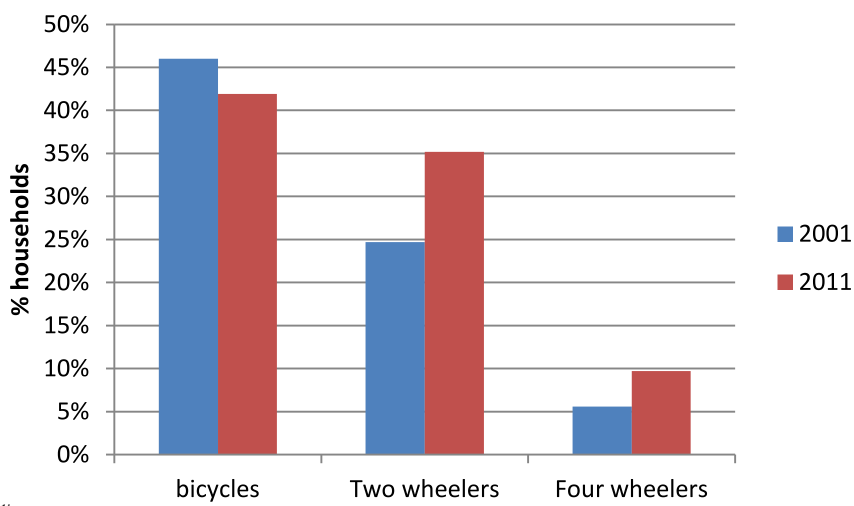
Source: CPCB, 2012

Note: Levels are classified into low, moderate, high and critical based on exceedance factor which is observed mean concentration compared to annual standard. When exceedance factor is below 0.5, it is considered in low category while above 1.5 is classified as critical

Indian transport is mostly dependent on liquid fossil fuels, most of which is imported. Transport accounts for about one-third of total crude oil consumption in the country, of which road transportation accounts for 80% (GoI, 2012). Consumption and imports of crude oil have increased exponentially in recent years. While the consumption has increased four-fold during 1991-2011, imports have risen eight-fold in the same period (MoSPI, 2012). Currently India imports close to 80% of its crude oil demand. In value terms, India's oil import bill has increased from Rs 4091 billion in 2009-10 to Rs 7264 billion 2011-12[14]. High share of imported fuel has implications for Indian economy and for its energy security.

Dependence on liquid fossil fuels also leads to increased emissions of greenhouse gases (GHG) which contribute to global climate change. Between 1994 and 2007, total GHG emissions from India went up by more than 40%, while those from transport sector increased by more than 77% (MoF, 2012).

Figure 3.3: Vehicle Ownership among Urban Households in India



Source: Census of India

14 http://www.pib.nic.in/newsite/erelease.aspx?relid=86628. Accessed July 28, 2014

Production of motorised vehicles in India has increased by more than 80% between 2007 and 2012. The percentage of households owning two-wheelers and four-wheelers has also increased between 2001 and 2011 (Figure 3.3). Despite this rise in production and ownership, the current level of vehicle penetration in India leaves a large room for growth. Current car ownership in India is 15 cars per thousand persons while two-wheeler ownership currently stands at 82 vehicles per thousand persons. Though this is lower compared to many developing countries, studies show that further increases are expected in motorized two-wheeler ownership.

Given the established two wheeler manufacturing industry, the expected growth in demand for vehicles, and the recent interest in EVs, India has the opportunity of strengthening domestic EV industry and emerging as a global leader in EV manufacturing market.

Current EV Market in India

The current market for EVs is very small in India. Though there are different types of E2Ws (scooters and bikes), E4Ws (electric cars), and electric buses, the overall share of EVs is negligible. In the 1990s, a couple of Indian firms introduced electric two- and three-wheelers in the market, but these were unsuccessful and were discontinued later.

The Reva Electric car company introduced the first electric car *Reva* in India in early 2000s which continues to sell a few units. Reva Electric focused on creating affordable electric cars through advanced technology and launched its first model in India in 2001 and in London in 2004.

The firm was later acquired by a large Indian automobile firm which launched a revamped version of the car in 2013. Powered with Lithium ion batteries, the new model allows for a top speed of 80 km/hr and a driving range of 100 km with a single charge. With a charging time of 5 hours, it is marketed to provide significant cost savings over a conventional car[15]. In 2010, Toyota introduced the Prius Hybrid model in the Indian market and has followed it up by introducing Camry Hybrid in 2013. Recently, a couple of Indian firms have announced plans to introduce electric cars in the short to medium term (Banerjee, 2013; Tata Motors, 2012). Hybrid and electric buses have been are being introduced as pilot initiatives in a few cities. The Bangalore Municipal Transport Corporation has recently introduced an electric bus on a dense corridor in the city. More recently, electric rickshaws are gaining popularity as a good substitute for conventional three-wheelers (rickshaws) and paddle-rickshaws. In Delhi alone there are more than 100,000 e-rickshaws and therefore, to regulate their use and address safety concerns, government has made amendments of the Motor Vehicle Act in 2014. Due to these amendments e-rickshaws must be registered and the drivers are required to have driving licenses.

Around the year 2000, only a couple of electric two-wheelers were available in the Indian market. However, the market has expanded and over two dozen different two-wheelers are available in the market at present. These include low speed vehicles with a maximum speed of 25km/hr to high speed vehicles capable of achieving speeds up to 65km/hr. The driving range varies from 20km to 100km.

15 http://mahindrareva.com/product/explore-the-e2o.aspx. Accessed June 25, 2014

EV market in India is still at a nascent stage. However, technology and battery advancements are making EVs more attractive to consumers due to increasing convenience and affordability.

Efforts are underway by electric vehicle manufacturers to provide options that can reduce charging time and increase awareness among consumers regarding lower fuel and maintenance costs of E4Ws compared to conventional cars. A preference survey carried out in Ludhiana city showed that 36% existing car and two-wheeler owners were willing to shift to electric vehicles. The preference of the respondents was higher for electric two-wheelers compared to electric cars (Grover et al., 2013).

The positive sign for EVs is that they have already arrived in urban transport, particularly in case of two- and three-wheelers. The penetration of electric three-wheelers in Delhi is significant. It is worth noting that this was not triggered not in response to any government intervention, but by their cost competitiveness and convenience to the drivers. Three-wheeler manufacturers have already found solutions to procuring locally produced batteries.

EV Policy and Initiatives in India

The government of India recognizes the urgency to look at sustainable mobility solutions to reduce dependency on imported energy sources, reduce GHG emissions and mitigate adverse impacts from transportation. In order to mitigate these, a portfolio of interventions have been planned which includes fuel efficiency improvement of vehicles, improving inspection and certification systems for reducing emissions from on-road vehicles, urban planning improving mass transport, shift to alternative fuels and technologies including biofuels and electric vehicles, and overall system efficiency of infrastructure.

As part of the Alternative Fuel for Surface Transportation programme, the Ministry of New and Renewable Energy (MNRE) promotes research, development and demonstration projects on electric vehicles. Recently, India launched the National Electric Mobility Mission Plan (NEMMP) aimed to incentivise electric vehicle production and sales with a total proposed investment of Rs 224 Billion (equivalent to US$ 4 Billion) by 2020 (Box 1). The key strategies proposed in the NEMMP are shown in Table 3.1.

Box 1 National Electric Mobility Mission Plan

National Electric Mobility Mission Plan (NEMMP) 2020 was announced by the government of India with the objective of enhancing national energy security, mitigating the adverse impact of vehicles on environment and growth of domestic manufacturing capabilities (GoI, 2012). The Plan envisages the following:

- A total investment of $ 4 – 4.5 billion which includes investments in R&D and electric vehicle infrastructure by the private sector. Proposed Investment by the government is $ 2.7 – 3 billion.
- Government investment will include roll out of demand incentives. Joint government-industry investment will include investment in R&D, power infrastructure and fuel procurement for power generation
- 6-7 million units of new vehicle sales of the full range of electric vehicles, along with resultant liquid fuel savings of 2.2 – 2.5 million tonnes can be achieved.
- Savings from the decrease in liquid fossil fuel consumption as a result of shift to electric mobility alone will far exceed the support provided thereby making this a highly economically viable proposition.
- Substantial lowering of vehicular emissions and decrease in carbon dioxide emissions by 1.3%-1.5% in 2020 as compared to the status quo scenario.
- Phase-wise strategy for Research and Development, demand and supply incentives, manufacturing and infrastructure upgrade

Table 3.1: Key Initiatives & Strategies under the National Electric Mobility Mission Plan (NEMMP 2020)

Focus Area	Interventions
Demand Creation	Working group on demand and supply to look at demand and supply incentives, hybrid retro fitment kits, to develop schemes, timelines and milestones Look at possible options for including a cash incentive to Original Equipment Manufacturers (OEM), tax incentive to OEMs, cash incentive or tax exemption to consumer
Research and Development	Collaborative approach between academia, research institutes, industries and government Working group of stakeholders to detail out the implementation Setting up of enabling rules, guidelines and policies Identifying specific R&D projects, resources required, prioritization and phasing Identifying areas and agencies for international cooperation Three subgroups in the area of Battery Management Systems (BMS) and batteries, power, electronics and motors and testing infrastructure/HR/efficient technologies
Manufacturing	Phase I: Start with local assembly of EVs with local or imported products and increase local sourcing. Industry government collaboration in R&D and product development centers Phase II: Developing indigenous products. 25-30% of EV products sourced locally Phase III: Industry to develop indigenous manufacturing capability. Phase IV: Target the export market
Charging Infrastructure	Phase I: preparatory phase, evaluation of options, assessment of innovative energy delivery business options including battery swapping, smart metering, putting in place the framework, enabling policies, charging infrastructure standards and laws Phase II: Deeper impact assessment studies, roll out pilot projects in cities, consortium building, testing of various strategies and models, business models for recycling of batteries, finalizing standards for infrastructure Phase III: Ensure reliable electricity supply, adequate recharging facilities with convenient access, viable business models, linkage between EV charging infra and RE supply systems, public charging infrastructure

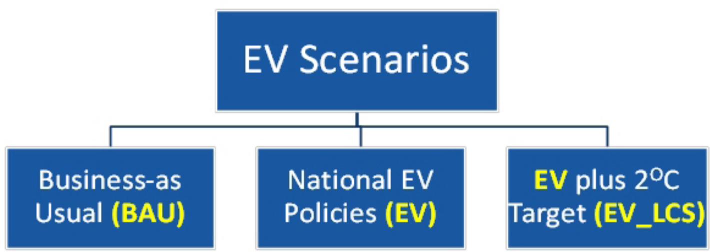
Source: GoI (2012)

Source: https://www.flickr.com/photos/traftery/5654312446

4. Future Scenarios

The report analyses three future scenarios for electric vehicles (Figure 4.1). In all three scenarios the economic and demographic transitions are kept the same. The annual GDP growth rate is 8% for the time period 2011-2032 and consistent with economic growth projections created for the Government of India (GoI, 2006) for the 2007-2032 period. Population growth and urbanization are assumed to follow the UN median demographic forecast (UNPD, 2013).

Figure 4.1: Scenario Architecture for EV Scenarios



The demand for transportation is also assumed to be the same across the three scenarios. Table 4.1 shows the transportation demand for road transport. The methodology for demand estimation is described in Dhar & Shukla, forthcoming.

Table 4.1: Transport Demand from road transport (billion pkm or billion tkm for freight)

Mode	2010	2015	2020	2025	2030	2035
Non-motorised transport	220	249	295	337	387	431
2-Wheeler	1041	1510	2062	2489	3155	3728
of which urban	*256*	*347*	*441*	*636*	*783*	*1029*
3-Wheeler	134	147	262	379	380	371
4-Wheeler	508	738	1058	1489	2054	2770
of which urban	*44*	*103*	*172*	*276*	*404*	*589*
Bus	4039	5231	6553	8268	10012	11759
Goods LCV	94	137	197	260	336	386

Scenario Storylines

Business as Usual Scenario (BAU)

Electric vehicles have caught the imagination of policy makers and automobile manufacturers globally. Globally many cities have launched initiatives for hybrids and electric vehicles (Appendix A). The Ministry of Heavy Industries has already announced a comprehensive road map for electric vehicles (GoI, 2012). On account of these changes at global and national level in the BAU we consider a reduction in the cost of electric vehicles[16] (Appendix B).

Electric vehicles in India face barriers on account of consumer perception with regard to charging time, driving range of non-hybrid EVs, battery replacement costs, top speed and acceleration (GoI, 2012). Some of these challenges can be overcome by vehicle variants based on Li-ion batteries; however, their high capital costs become a barrier in such cases. Charging speed and range are related to technology and infrastructure for charging. Higher charging speed can be achieved through special charging points[17] and similarly the driving range can be addressed by choosing batteries with higher specific energy (Figure 2.6) or through a well distributed infrastructure for charging and supply of replacement batteries. The BAU scenario assumes that the less expensive technology options which have limitations vis-à-vis charging time and driving range (e.g. E2W using lead acid battery) are limited to servicing urban transport demand where trip lengths are shorter and therefore driving range is not a major concern. In case of advanced and more expensive technology options, e.g. those with a higher driving range, no constraints are imposed since their penetration shall be decided by cost competition.

The BAU scenario considers that cities will develop better public transport infrastructures therefore a rapid growth in demand for bus-based transport is projected until 2030 (Table 4.1). Air quality is a key concern for cities; therefore, it is assumed that incentives will be provided for electric buses. These are limited in the model to the volume of buses mentioned in the National Electricity Mobility Mission Plan (NEMMP) 2020 (See Table 4.2).

Table 4.2: Capital Subsidy on EVs proposed in NEMMP 2020

Vehicle Category	Subsidy Range (INR) per vehicle	Limit per year(Units Sold)
E2W	5,000 – 15,000	1,000,000
Hybrids & E4W	25,000 – 150,000	200,000
Hybrids & E Bus	500,000 – 3,700,000	900

Electric and hybrid vehicles purchased by private buyers currently do not receive enabling support (Table 4.3). The demand-side incentives are assumed to be available from 2015 only in the EV Policies Scenario and not in the other scenarios since the NEMMP recommendations are yet to be implemented.

16 Mainly due to the reduction in battery costs which are expected to come down to less than half of today's levels in the next 10-15 years (Bloomberg New Energy Finance, 2012)

17 For example, Tesla provides special charging points for its EV consumers <http://www.teslamotors.com/charging#/highpower>

Table 4.3: Policy Instruments in BAU and EV Scenarios

Policy Instrument	BAU Scenario	National EV Policies Scenario
Economic Instruments for EV		
Excise Duty / Import Duty	A duty of 12% applies to EV and hybrid cars. This is at par with small gasoline or diesel cars (engine capacity less than 1500 cc and length less than 4m). Batteries, motors and other parts for EV have no preferential treatment.	Considers full duty exemption till 2025 on cars and batteries. Post 2025 tax rates increased and tax parity is achieved by 2040.
Sales Tax (VAT)	No concessions for VAT considered.	Considers half the VAT in BAU to factor for the positive local environmental benefits till 2025 and thereafter an increasing tax rate with tax parity by 2040
		Overall a lower capital cost compared to BAU.
Incentives for Public Transport		
Buses	In BAU, priority for buses and BRT systems is expected in all cities with more than a million inhabitants however no special incentive for electric buses.	Capital costs lower due to economic incentives and better provisioning of infrastructures for charging.
Infrastructures for EV		
Charging infrastructures	The BAU considers no specific investment into charging infrastructures and as a result EV makes use of spare capacity of grids. Therefore a maximum share constraint of 20% put on 2W and cars by 2035.	An intelligent electric grid which can allow usage of EV both as storage and source of electricity combined with a higher capacity grid. As a result a 10% higher investment on transmission & distribution is assumed. Meanwhile maximum share of EVs among 2Ws and cars is increased to 40% by 2035.
Dedicated lanes for cycles	Funding from central government is expected to help create cycle lanes and a better infrastructure for cycles in the cities. Motorized 2-wheelers, however, are not allowed on cycle lanes.	E2W with maximum speed of 25 km per hour allowed on the cycle lanes. This would increase attractiveness of E2W and shift non EV bicycles to EV.

National EV Policies (EV) Scenario

Electric vehicles can deliver multiple co-benefits (improved air quality in cities, energy security, renewable integration, etc.). This scenario assumes that governments recognize these aspects of EVs and support their penetration. Therefore the scenario considers that there will be domestic policy support (See Table 4.3) for EV which improves their competitiveness. The scenario, does not limit itself to the quantitative limits set in NEMMP 2020 since these are very meagre (e.g. more than 10 million 2-wheelers were sold in 2010 and therefore limiting to 1 million units is not going to bring a significant change especially since the demand for two-wheelers in 2020 would be more than 30 million). The scenario assumes that the support will be slowly reduced and completely removed by 2035. The types of policy support include duty waivers, sales tax reduction, creation of smart grids and charging facilities. Governments also provide greater incentives for research and development in battery technologies, EV drive trains and smart grid technologies. Smart grids enable usage of EVs as storage and help in integrating renewables.

The scenario also assumes a global push for EVs that result in advancements in battery technologies, improvements in battery capacities, declining component costs, and economies of scale in production, all of which leads to a reduction in EV costs.

A key reason for India to be at the forefront of research in EV technologies is that the nation has relatively low domestic oil availability. Hence R&D in energy efficient and alternative fuel technologies can deliver added benefits: mitigating energy security risks in India (Kim, 2014), and creating market access opportunities for south-south transfer of technologies.

EV Low Carbon (EV LCS) Scenario

EVs can increase or decrease the emissions from transport, depending on the CO_2 content of electricity. Electricity carbon footprint can get substantially altered if there are stringent climate targets (Shukla & Dhar 2011). This scenario combines the EV policy support together with a high carbon tax corresponding to the globally agreed vision of 2°C stabilization target. The trajectory for CO_2 price is along a pathway which is aligned with the Copenhagen pledges which will come into force post 2020. The CO_2 price trajectory therefore is at a low level of 13.9 US $ per t CO_2 in 2020 and then increases steadily to reach 200 US $ per t CO_2 by 2045 (Lucas et. al., 2013). The scenario considers no constraints on the share of EVs in the vehicle fleet.

Methodology

Assessing the role of EVs in the long term involves analysing cost competitiveness with other vehicle technologies and also interaction with different energy markets (e.g. electricity markets, renewables, coal, oil markets, and gas markets). It also requires a detailed representation of the technologies involved. A bottom-up modelling framework such as MARKAL is quite well suited for this. The ANSWER MARKAL model (Loulou et. al., 2004) has been used extensively for assessment of Indian energy sector (Shukla et. al., 2009), renewable energy (Shukla et. al., 2011) and climate policies (Shukla & Dhar, 2011; Shukla et. al., 2008). The model allows for a rich characterisation of the electricity sector, and is set up to study long term transitions up to 2050.

Modal choices within the transport sector depend on investments into infrastructure (e.g. rail, road, metros etc.). These modal transitions are handled separately (see Dhar & Shukla, forthcoming) and provided as an exogenous input to the MARKAL model. In the ANSWER MARKAL model only the competition between alternative technologies for a given mode is handled (e.g. between Electric cars and Petrol Cars).

Results

Share of Electric Two-wheelers

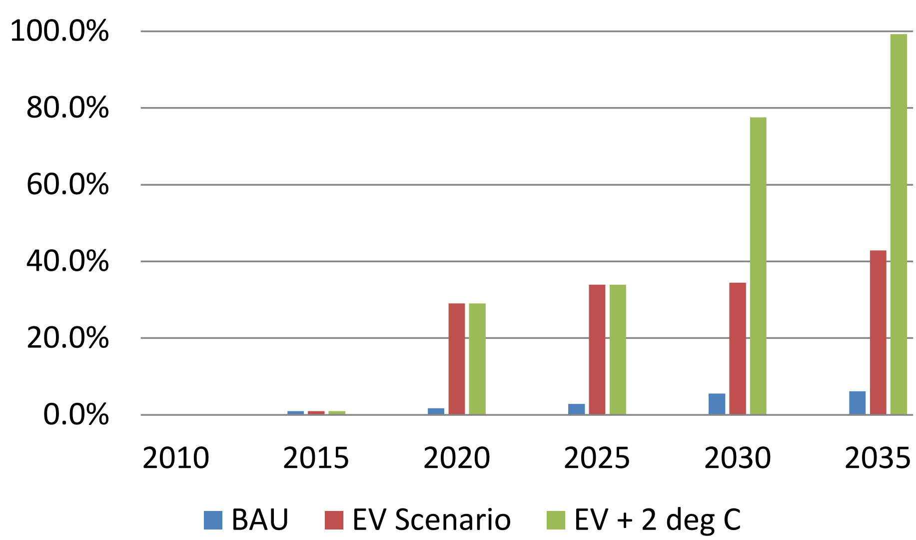
Two-wheelers are a major mode of transport and are expected to continue to remain a major mode of transportation in cities (Table 4.1). Motorized 2-wheelers mainly use petrol as fuel with 2-stroke or 4-stroke internal combustion engines. In the BAU electric bicycles (Technology 1a, Appendix B) would become viable from 2020 onwards; however, since they have a limited driving range and payload capacity, E2W wheelers play a limited role in terms of overall transport demand. Electric scooters and motorcycles, which are expensive but have a much larger battery, bigger payload capacity and a longer driving range, do not penetrate the market until 2030 in the BAU scenario.

In the EV scenario, due to the financial incentives for electric vehicles, improved infrastructures for charging and other local incentives (Table 4.3), cheaper E2Ws (such as Technology 1a & 1b) find earlier and higher market penetration. There is a jump in the share of EVs relative to BAU from 2020, while post 2025 further increase in the share is slow. This is due to the fact that these cheaper variants have limitations with regard to driving range and power and are therefore limited to driving within cities. The more expensive variants which have driving range and payload capacity comparable to conventional 2-wheelers do not become competitive against the conventional 2-wheelers. Electric hybrid 2-wheelers also do not have sufficient incentives to overcome barriers in this scenario.

The penetration of EVs increases in the EV scenario with financial incentives and better infrastructures. In the EV + 2°C scenario even expensive E2Ws become competitive with conventional vehicles

In the EV plus 2°C stabilization scenario even more expensive E2W (e.g. Type 1c, Appendix B) become a competitive option along with hybrid electric two-wheelers and by 2035 nearly all two-wheelers are either full electric or hybrid (Figure 4.2).

Figure 4.2: Share of Electric and Hybrid 2-wheelers



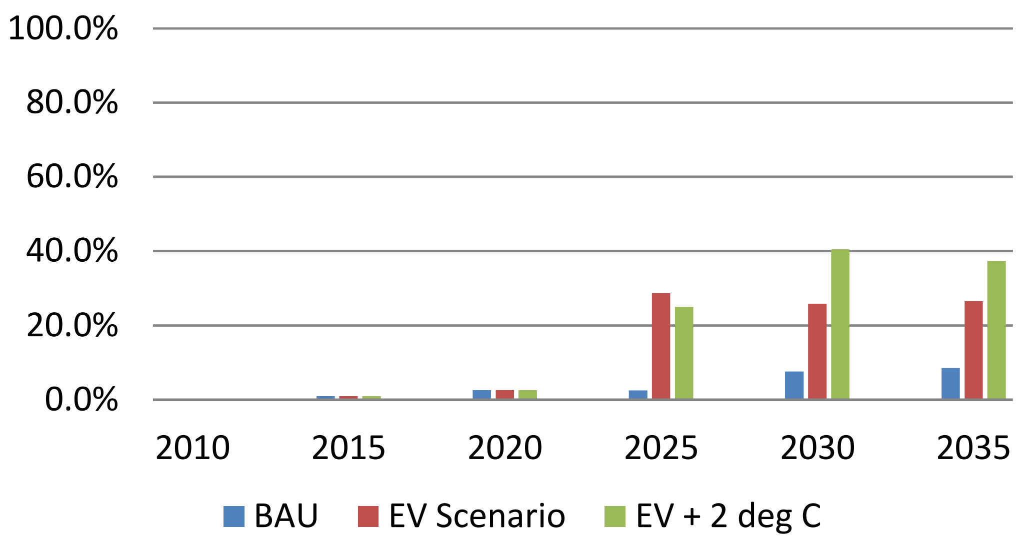
EV 4-Wheelers

Four-wheelers are emerging as a major mode of transport, including in the cities (Table 4.1). Four-wheelers mainly use gasoline or diesel as a fuel though in the last decade, due to the emergence of gas distribution networks in a number of cities (Dhar & Shukla, 2010), CNG four-wheelers have also gained a significant share in the vehicle fleet. E4Ws currently have a negligible share of the market. In the BAU scenario small electric 4-wheelers (e.g. technology 2a, Appendix B) with a price below 15,000 USD would become viable from 2030 onwards; however, since they have a limited driving range and payload capacity these models are limited to service transport demand within cities and only a small share of intercity demand (see constraints on Technology 2b, Appendix B). Electric four-wheelers with a much larger battery, bigger payload capacity and a longer driving range (e.g. technology 2b, Appendix B) do not become viable by 2035.

In the EV scenario, due to the incentives for electric vehicles (Table 4.3), small electric cars become viable from 2020 onwards. However, their diffusion is limited owing to the limitations of vehicles (driving range, payload).

In the EV plus 2 °C scenario a higher carbon price puts EV 4-wheeler at a disadvantage until 2025, since CO_2 content of electricity is still high. However, as electricity starts to decarbonise, EV penetration increases beyond the penetration achieved in the EV scenario. Nevertheless, even the higher carbon price is not able to ensure viability for more expensive EVs that are comparable in features to conventional vehicles.

Figure 4.3: Share of Electric, Hybrid and Fuel Cell 4-Wheelers

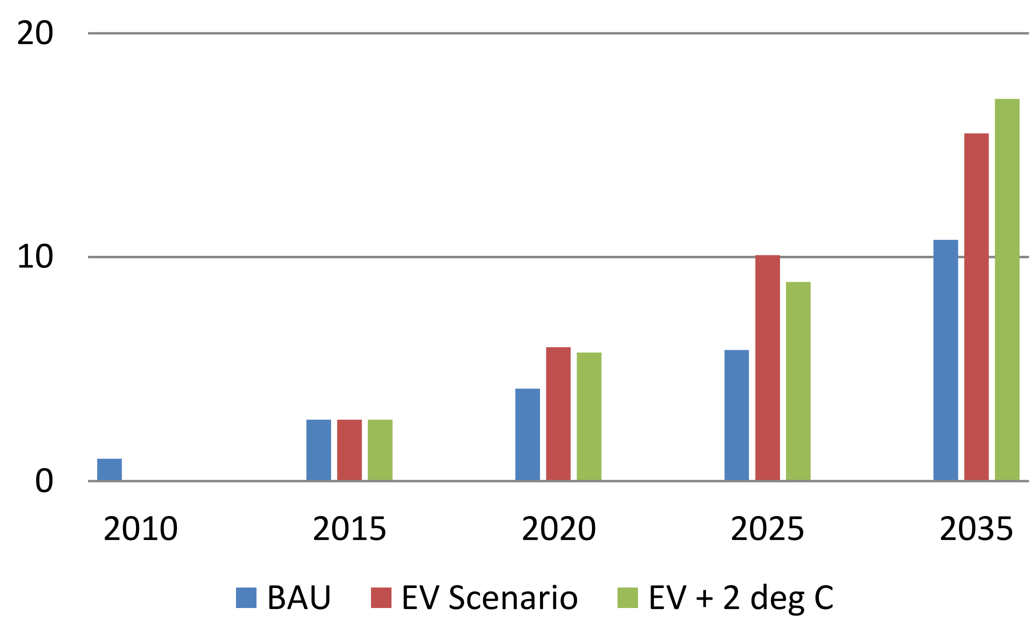


Electricity Demand and Fuel Mix

Electricity demand for transport has traditionally come from rail transport. In the future, demand for electricity from rail transport will increase, so that in the BAU scenario around 48% of electricity demand comes from rail based transport. The remaining demand for electricity comes from public transport in cities (trams, electric buses and metros) and private transport (electric two- and four-wheelers). In the BAU scenario the demand for electricity from electric two-wheelers and four-wheelers accounts for 15% of overall demand in 2035 (Figure 4.4).

In the EV scenario the demand for electricity from transport is higher than in the BAU scenario due to a rapid diffusion of E2Ws and E4Ws. By 2035, the share of electric 2/4 wheelers accounts for 41% of electricity demand from transport and replaces rail based transport as the highest demand for electricity. In EV plus 2°C scenario the share of E2Ws and E4Ws in electricity demand is even higher reaching 47% of electricity demand by 2035. The EV plus 2°C has a much lower overall demand for electricity than the EV scenario due to a lower share of E2Ws and E4Ws wheelers.

Figure 4.4: Electricity Demand for transport (Mtoe)



The increase in demand for electricity from transport would be an opportunity for electric grids. In the EV plus 2 ° C scenario the overall demand for electricity from transport reaches 198 Twh in 2035. The increased demand for electricity is complemented by a distributed storage of a similar or higher magnitude in the system. This could help in better integration of intermittent renewables like wind and solar.

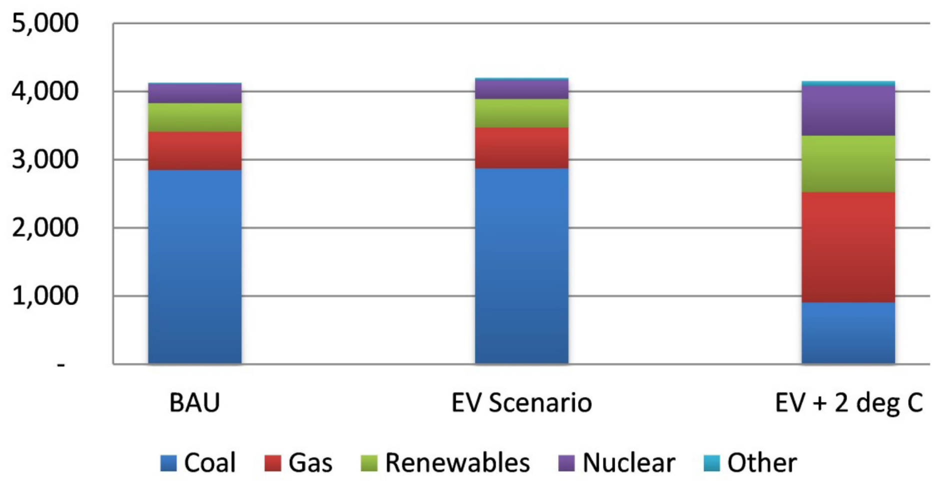
In EV plus 2 ° C scenario where the share of EV is highest, the demand for electricity from transport as a percentage of overall electricity output increases from 1.2% in 2010 to around 5% in 2035. Therefore to achieve EV growth offered by this scenario, major capacity additions in the electricity sector would not be required.

The fuel mix in the electricity sector is similar in BAU and EV Scenarios. However, higher battery storage made available in the EV scenario, could give flexibility for transmission system operators, if used together with smart grids. In

Rapid diffusion of EVs in the EV and EV +2 ° C scenarios will increase electricity demand; however this will not require major capacity addition.

EV plus 2° C scenario, coal ceases to dominate to be replaced by renewables, natural gas and nuclear generation (Figure 4.5). In addition to that, CCS penetration further decarbonises fossil fuel generation and by 2035, 99% of coal based capacity is with CCS.

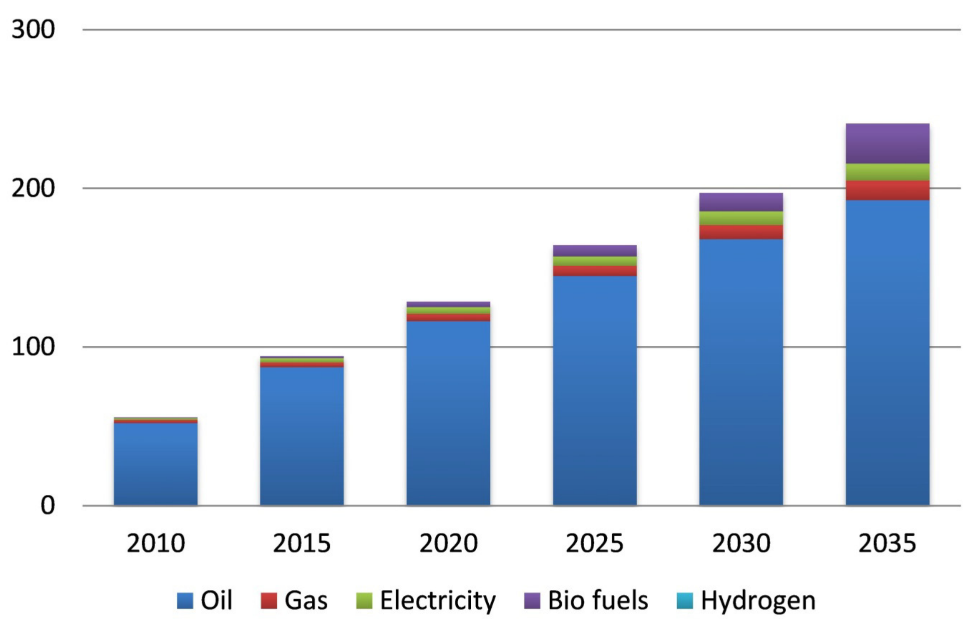
Figure 4.5: Electricity Output (TWh) by Fuel Type in in BAU, EV & EV + 2°C Scenarios



Energy Demand for Transport

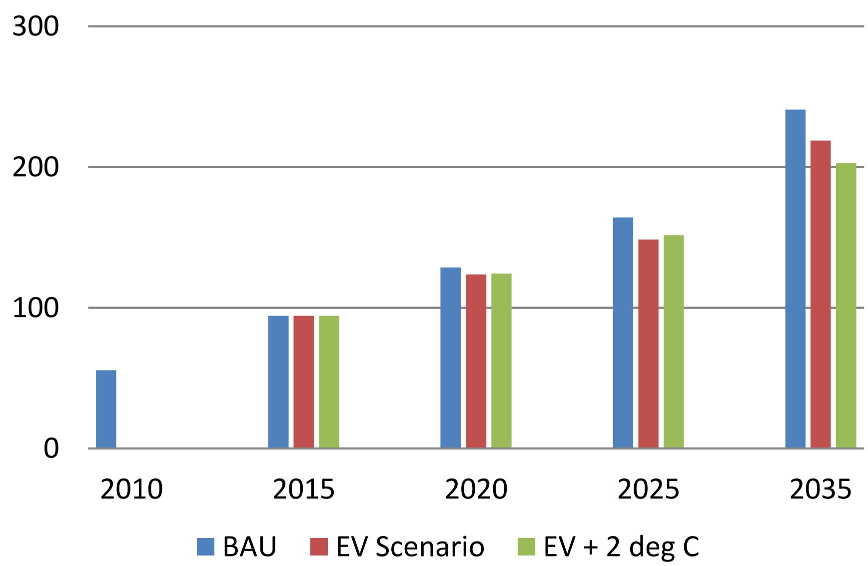
In the BAU scenario, the overall energy demand from transport increases nearly 4.3 times between 2010 and 2035 (Figure 4.6). The overall dependence on oil (petrol, diesel, LPG) continues although there is diversification towards natural gas (CNG) and bio-fuels. Electricity demand increases significantly post 2020. Hydrogen as a fuel was also provided as an option (hydrogen fuel cell cars and buses), but is not viable in the 2035 horizon.

Figure 4.6: Final Energy Demand (Mtoe) for transport in the BAU Scenario



The benefits of EV for energy security are visible from 2025 onwards in the EV and EV plus 2° C scenarios (Figure 4.7) as the overall demand for energy goes down compared with the BAU scenario. The benefits for energy security also accrue due to a diversification of fuel mix away from oil. In the EV scenario the demand for oil in 2035 is lower than in the BAU scenario by 23Mtoe. In the EV plus 2 ° C scenario this difference is 39 Mtoe. For both scenarios this is accompanied by an increase in demand for electricity (Figure 4.4).

Figure 4.7: Final Energy Demand (Mtoe) for Transport in BAU, EV & EV + 2°C Scenarios

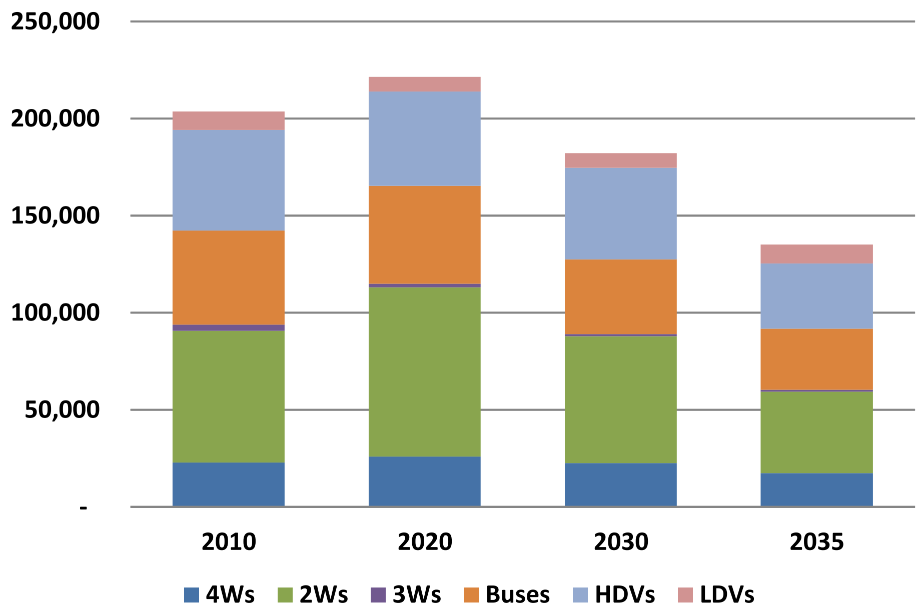


Local Pollutants

In the BAU scenario, the emissions of PM 2.5, a key local pollutant, increase until 2020. A key driver for this is an increasing two-wheeler population along with cars and other motorised transport (Figure 4.8). Therefore in the BAU scenario, air quality inthe cities is expected to deteriorate in the short term. However, improvement in emission standards in the medium term (Euro 4 standards by 2020 all across India) and replacement of older vehicle stocks will lead to a reduction in local pollutants (such as PM 2.5) by 2030 and beyond.

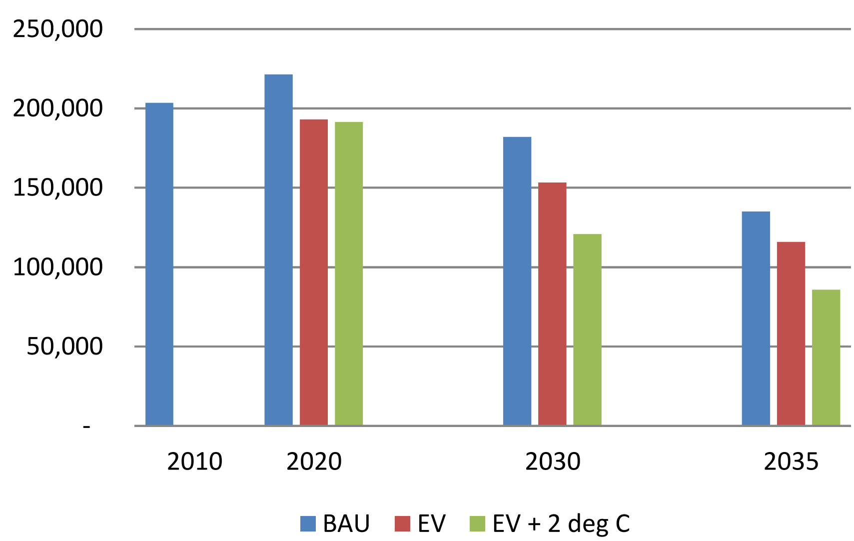
EVs can deliver significant local air quality benefits in the short and medium term. In the EV plus 2°C scenario the emissions of PM 2.5 will fall below half of the current levels

Figure 4.8: PM 2.5 Emissions (tonnes) from Transport in the BAU Scenario



If incentives are provided for EV, as modelled by the EV and EV plus 2°C scenarios, local pollutant emissions can be brought down earlier and therefore help in addressing the challenges in the short term. Sharper declines in pollutant emissions are achieved in the medium term. In the EV plus 2°C scenario, the benefits for local air quality are particularly significant, indicating a decrease in emissions of PM 2.5 to below half of the current levels by 2035 (Figure 4.9).

Figure 4.9: PM 2.5 Emissions (tonnes) from Transport in BAU, EV & EV + 2°C Scenarios

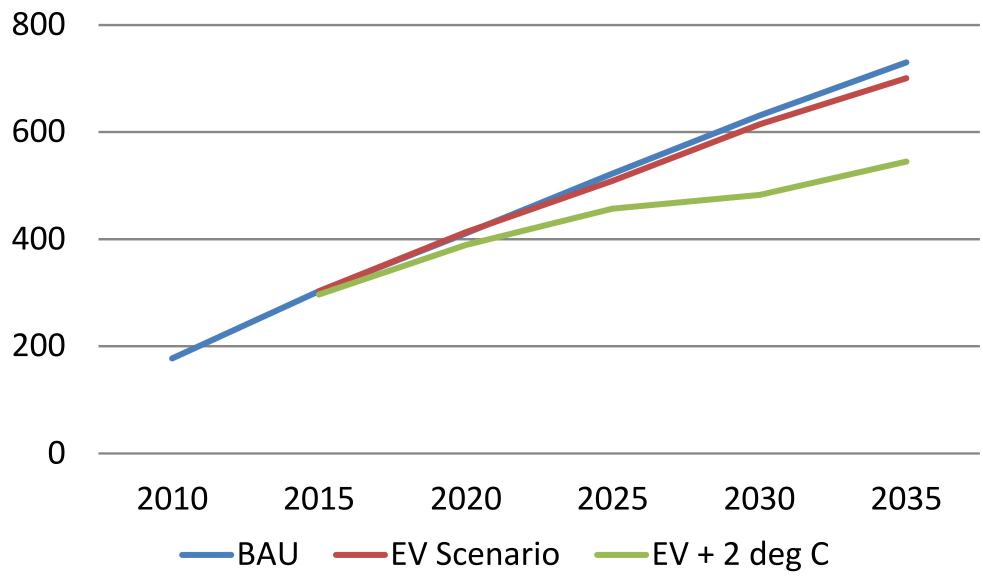


CO_2 Emissions

CO_2 emissions increase over four-fold between 2010 and 2035 which is slightly smaller than the increase in energy demand. The decoupling between energy and CO_2 emissions is due to the diversification of fuel mix towards biofuels and natural gas, and reduction in CO_2 intensity of electricity. The CO_2 intensity of the grid decreases from 0.80 Million tCO_2 per GWh in 2010 (CEA, 2012) to 0.75 Million t CO_2 per GWh in 2035 in the BAU scenario.

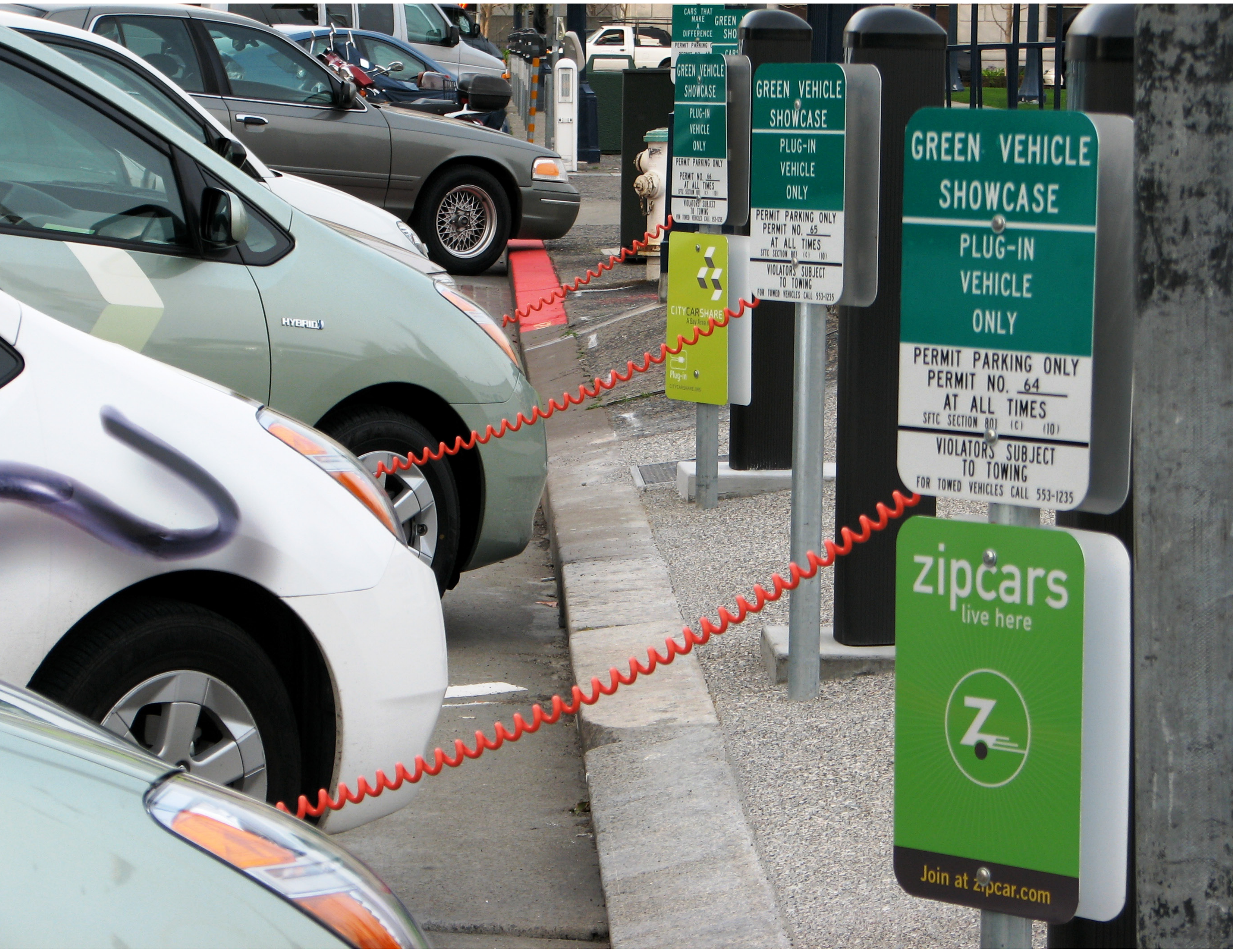
In the EV scenario, only a slight reduction in CO_2 emissions is achieved (Figure 4.10), since the electricity remains CO_2 intensive. Meanwhile in the EV plus 2°C scenario, a greater downward shift in CO_2 emissions is observed[18]. This is for two reasons: first, CO_2 emissions from electricity generation are significantly lower in this scenario, and second, overall energy demand is lower due to adoption of more efficient vehicles. The decarbonisation of electricity is slow early in the time horizon, but is reduced faster post 2025 and is only 0.17 Million tCO_2 per GWh in 2035. The decarbonisation of electricity is achieved through a major shift in the electricity sector away from coal (Figure 4.5) and deployment of CCS.

Figure 4.10: CO_2 Emissions (tonnes) in BAU, EV & EV + 2°C Scenarios



Decarbonisation of electricity in the EV plus 2°C scenario will bring down CO_2 emissions from transport

18 In addition to vehicle technologies, the reductions in CO_2 emissions require changes in fuels and infrastructure. Since the focus of this work is on EVs, these scenarios are not analysed in this report. However, these have been analysed in a separate paper produced as a part of the project (Dhar & Shukla, forthcoming).



Source: https://www.flickr.com/photos/56727147@N00/3292024112

5. Roadmap

In the Indian context, the Electric Vehicles (EVs) have the potential to deliver benefits for energy security and local environment. EVs are a suitable option for CO_2 mitigation provided that electricity is decarbonized. In the low carbon future, to meet the global 2^{o}C stabilization target, the entire national electricity supply must be decarbonized. This may take a couple of decades, to permit the turnover of the existing capital stock of fossil-based electricity generation. In the immediate future, the policies to shift to EVs shall deliver sizable local pollution benefits. This report has presented the assessment of impacts of various policies on the diffusion of EVs in India; their consequent implications for India's energy mix, local air pollution loads and CO_2 emissions and the nature and scale of actions needed to respond to the global low carbon target as well as national policy goals.

EVs' market share in India is still small. In terms of sales, the EVs in the Indian market are exhibiting a pattern similar to China's where E2Ws have a higher market penetration than E4Ws. It might indicate that in the coming decade, the growth pattern in India will be similar to that observed in China during the past decade. Recently, a rapid uptake of E3Ws has occurred in Delhi and some other cities. This was triggered by favourable economics offered by these vehicles and not in response to specific government interventions that are still in the making.

National

Demand Incentives

To become competitive, EVs need to be supported by fiscal concessions (e.g. Sales Tax, Excise and Customs Duty). The analysis of the EV scenario, which models such fiscal support, shows that if the capital costs of EVs were brought down by around 30% from the BAU, then a major shift to EVs would happen. The revenues that government would need to forego to provide this support would be 2803 billion INR for the period until 2035 (Table 5.1). To incentivise demand would cost 371 billion INR before 2020 (i.e. in the period planned for in the NEMMP). This is higher than the 233 billion proposed in NEMMP for demand creation, R&D, power infrastructure and fuel purchase. The revenue losses would decline as the demand-side incentives reduce over time.

Table 5.1: Loss of Revenues (Rs Billion)

	2015-2020	2020-30	2030-35
Two-Wheelers	189	392	213
4-Wheelers	6	671	606
Buses	177	391	158
Total	371	1,454	978

Providing financial support for EVs is not sufficient for low carbon transition. For this to have positive effect on transport emissions, it should be accompanied by decarbonisation of electricity. This response can be triggered by setting a carbon price signal corresponding to the globally agreed climate stabilization target over the national economy.

Industrial Policy

Economic incentives should be accompanied by policies for building domestic capabilities for EV manufacturing. NEMMP 2020 already has elements of this, although the ambition needs to be higher if EVs are to deliver their full potential.

Smart Grids: Investment

Investment in smart grids would enable the use of EVs as storage of electricity. This could lead to efficient pricing of electricity, better integration of intermittent renewables and hence a more sustainable electricity sector. There is a lot of focus on renewables currently and the target for grid based solar is put based power is put at 20 GW by 2020 under National Solar Mission. Integration of electric mobility in urban policies and plans would facilitate sustainable urban energy transitions and deliver early benefits. However, smart grid requires substantial investments. The precise scale of investments is uncertain since there is limited experience in their implementation. According to a study on the US electricity grid, the costs for consumers can go up by 8.4-12.8% (EPRI, 2011). In India, a 10% higher grid investment, compared to the BAU scenario, would require 1,441 billion INR (cumulative until 2035). This would add sizable storage capacity in the immediate future (Table 5.3) which could make EVs a source of electricity for critical household appliances during the power shortage.

Table 5.2: Additional Investments for smart grid (Rs Billion)

2015-2020	2020-30	2030-35
494	652	295

NB: The electricity capacity in the BAU increases to 776 GW by 2035 and the grid investments have been calculated in BAU at the rate of Rs 20 million per GW.

Batteries: Security of Supply and Disposal

EVs play a big role in the EV and EV plus 2° C scenario. The future EVs will however use lithium batteries, with higher energy density[19] and battery life and lower environmental impact. The rising demand for batteries (Table 5.3) would require Giga watt sized manufacturing facilities.

19 Lithium Ion batteries typically have an energy density of 100 – 500 Wh per kg. This means that the weight of 1.2 KWh battery used in an electric bicycle would weigh between 12 kg and 2.4 kg.

Table 5.3: Battery Demand in the EV Scenario (GWh)

	2015-2020	2020-30	2030-35
Two-Wheelers	94	79	41
4-Wheelers	1	66	79
Buses	6	24	18
Total	100	169	138

NB: Battery capacities are calculated on the basis of investment levels for different technologies within the model.

India does not have substantial lithium resources and therefore would need to establish a reliable supply-chain. Moreover, facilities would be needed for the collection and recycling of the batteries. Policies to promote private and public initiatives to address these needs are vital to support the rising EV stock in the country.

R&D funding

To support a growing EV industry the government would have to provide research grants in the areas of battery technology, vehicle technology, smart grids and charging infrastructures. Other vital areas of R&D include distribution centres for charged batteries, recycling and reuse of batteries, use of EV for improving energy access and integration of electricity from intermittent sources.

Standards

A number of players in the domestic industry are investing into EVs. The government can create enabling conditions for the sector by putting into place common standards for charging infrastructure (devices and batteries) so that charging infrastructure is not used by larger players to attain and retain advantage in the market.

CO_2 Mitigation

The role of electric vehicles in mitigation of CO_2 emissions is closely related to the CO_2 content of the electricity. Strong climate policies can achieve a big reduction in CO_2 intensity of electricity. As shown by modelling EV plus 2°C scenario, CO_2 intensity reduces from 0.8 tCO_2 per GWh in 2012 to 0.17 Million tCO_2 per GWh in 2035 due to a high carbon tax. Cleaner electricity reduces CO_2 emissions from EVs.

Cities

EVs have significant advantages for cities which are facing a big challenge in ensuring cleaner air and providing transport access. Although a significant part of enabling environment for EVs needs to be created at the national level, cities can also play an important role in transition to EVs.

Stricter Emission Standards

Indian cities have adopted emission standards for vehicles to address the problem of air pollution within the cities. In the past, these policies have been very technology centric, e.g. ban on petrol and diesel three-wheelers, and promotion of CNG three-wheelers. In the future stricter emission standards could also provide a distinct advantage to EVs.

Charging and Parking

Parking space is scarce and expensive within the cities. If some parking spaces are reserved for EVs and charging facilities are provided in such parking spaces, it can incentivise EVs. It would also help address the barrier of driving range for EVs.

Prioritising EV in Traffic

Cities in India are constructing cycle tracks along BRT corridors. Slower moving E2W (speed less than 25 km/h) can be allowed on cycle tracks which can help them avoid congestion and improve their safety. EV 4-wheelers should be similarly given priority on congested roads along with public taxis and pooled cars.

EV for Para Transit and Bus System

Public transport is lacking in most of the Indian cities and demand for public transport is addressed largely by para-transit. Para-transit modes like auto rickshaws are a cause of air pollution in many cities. Cities can address their air quality problems by shifting some part of their fleet to EVs. Similarly, many cities are strengthening their bus systems and some share of these buses can be EVs. The cities can be supported for such initiatives by central funding. Karnataka, one of the progressive states in India, has already proposed exemption of road tax and VAT for electric vehicles. Bangalore Municipal transport Corporation recently concluded trial of an electric bus in the city.

Car Sharing

In some cities, car sharing companies working on a public-private model have been founded[20]. These companies offer electric vehicles on a rental basis and the vehicles are made available at strategic locations within the city. This allows for a greater utilisation of vehicles and is accompanied by construction of charging stations at parking places. Overall, this can address barriers created by high capital cost of cars and lack of charging infrastructure.

Financing of EVs via NAMAs

EVs, especially for para-transit and public transport can be recognised as a National Appropriate Mitigation Action (NAMA) due to their positive contributions for energy security, local environment, industrial development, renewable integration and CO_2 mitigation. Projects for promoting EVs can therefore access climate funds in addition to conventional sources of financing. In the long term, global climate policies, especially the carbon price signal, will encourage low carbon electricity and the demand for EVs will increase. Meanwhile, it is essential to have programmatic and institutional support at the national level for channelling funds to EV development through existing and emergent climate finance mechanisms.

20 For example Autolib is an initiative underway in Parishttps://www.autolib.eu/en/our-commitment/partners/

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End Notes

1: BYD e6 claims to run 400 km on a single charge (http://byd.com/na/auto/e6.html)

2: http://compare.nissanusa.com/nissan_compare/NNAComparator/Compare.jsp?clientID=273266&&tool=model.features.compare.button&#params:main=competitorselect-acode=XGC30NIC161A0

3: http://www.teslamotors.com/models/design

Glossary

Electric Vehicle (EV): Vehicles which use an electric motor, with or without an internal combustion engine (ICE) for propulsion. An on-board battery provides the energy to electric motor.

Electric Two Wheeler (E2W): Includes electric cycles, electric scooters, and electric motorbikes.

Electric Three Wheeler (E 3W): Includes electric rickshaws for passenger and freight movement.

Electric Four Wheeler (E 4W): Includes electric cars.

Battery Electric Vehicles (BEV): Electric vehicles which use only an electric motor, powered by on board- batteries, for propulsion.

Hybrid Electric Vehicles (HEV): Electric vehicles which use an electric motor (secondary propulsion source) in combination with an ICE (primary propulsion source). On-board batteries provide energy to electric motor while gasoline or diesel powers the ICE. In HEVs, batteries get recharged through either the power from ICE or from regenerative braking (essentially, the small battery size allows for this continual recharging). If HEVs allow external charging of batteries, it is then called PHEVs.

Plug in Hybrid Electric Vehicles (PHEV): A type of HEVs which have batteries of higher capacities and which generally have electric motor as the primary propulsion source. These vehicles allow charging of on-board batteries.

Fuel cell electric vehicles (FCEV): Advanced electric vehicles which are powered by energy obtained from a fuel cell instead of a battery. The fuel cell generates electrical energy by converting chemical energy of a fuel such as hydrogen.

Conventional Vehicle: Vehicles which use an Internal Combustion Engine (ICE) to drive the vehicle. The energy to ICE comes from petroleum fuels, i.e. gasoline, diesel, or compressed natural gas (CNG).

Battery Swapping: The process in which a discharged battery (battery whose energy has been consumed) is replaced by a charged battery.

Capacity (battery): A measure of the energy which can be stored in a battery. Its unit is kilo-watt hours (kWh).

Energy density (battery): A measure of the energy which can be stored in a battery per unit weight of the battery. Its unit is Wh/kg.

Specific Energy: This is same as energy density. But technically, energy density is a measure of energy stored per unit volume, while specific energy density is a measure of energy stored per unit mass.

Battery Capacities: Repeated (See 'Capacity' above)

Greenhouse Gases (GHG): The term refers to gases in the atmosphere which can absorb heat. The gases include CO_2, O_3, CH_4, N_2O, and chlorofluorocarbons (CFCs) and have different warming abilities which are defined in terms of global warming potentials.

PM (Particulate matter):"Particulate matter," also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles[1].

Bidirectional power transfer: Provision which allows transfer of power (electric energy) in two directions. In the context of EVs, it means that EVs can store electric energy from grid in the batteries, and can also transfer the stored electric energy back to the grid.

Internal combustion engines (ICE): An engine where combustion of a fuel occurs in presence of an oxidizer in a combustion chamber. In conventional vehicles, combustion of gasoline or diesel occurs in presence of air in the ICE.

Driving Range: A measure of the distance electric vehicles can cover on a single charge of battery.

Charging Time: A measure of the time taken to charge the battery to 100% from 0%.

Pay Load Capacity: A measure of the maximum load (weight) a vehicle can carry.

Smart Grid: "Smart grid" generally refers to a class of technology people are using to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation. These systems are made possible by two-way communication technology and computer processing that has been used for decades in other industries[2].

Zero Electric Vehicles: This should actually be zero emission vehicles (described below). This term appears on page 18 of the document and we would need to replace 'electric' with 'emission'.

Power Grid: A network of electric transmission system including transmission lines and transformers, which allows for the transfer of electricity from one point to other.

Grid Capacity: A measure of the maximum electric power which can be transferred by the grid.

1 US EPA www.epa.gov Accessed November 18, 2014

2 http://energy.gov/oe/services/technology-development/smart-grid Accessed November 18, 2014

CO_2 intensity of the grid: A measure of the average carbon dioxide released in producing electricity flowing in the grid. It is measured by the amount of carbon dioxide emitted for every unit of electricity that is generated and transmitted. Its unit is grams of CO_2/kWh.

Zero Emission Vehicle (ZEV): Vehicles which have zero tail pipe emissions. The California ZEV plan defines ZEV to include hydrogen fuel cell electric vehicles (FCEVs) and plug-in electric vehicles (PEVs), which include both pure battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs).

Para-transit: Para-transit is normally a mode of transport that fulfils a need that neither public transport nor personal vehicles are able to fulfil and are typically operated by private operators. Para-transit modes in India include a wide variety of vehicles - 3 wheeled shared autos (e.g. Vikram), minibuses, auto-rickshaw taxis, vans, etc.

Photo credit: Varun Shiv Kapur

Appendix

Appendix A: EV Support Initiatives: A snapshot from different countries

Initiative	Details	Example
Charging Infrastructure	Trialing public charging stations at community centres, shopping malls, curbs, and other locations throughout the city.	Vancouver[1]
Building by laws	20% of parking stalls in apartments and condos, and all stalls in houses to to be electric vehicle ready. New public car parks with 2 percent of the spaces reserved for electric vehicles and facilities ready for the future inclusion of points in the rest of the spaces.	Barcelona, Spain
Public Private Partnerships	Partnering with telecommunications companies to provide electric vehicle charging at sites where new cellular infrastructure is installed. Partnering with private organizations to develop projects for hybridization of buses and minibuses, and implementing 100 percent electric routes in neighborhoods with mobility difficulties. EV workshops for municipalities and residents	Vancouver, Canada Barcelona, Spain Los Angeles, USA
Economic Instruments	Tax benefits: up to 75 percent of vehicle registration tax. Free recharging for electric vehicles at all municipal points on public roads until the end of 2012. Subsidies of 20,000 RMB for plug-in hybrid electric vehicles and 40,000 RMB for pure electric vehicles	Barcelona, Spain Shanghai, China
IT	Innovative projects for smart e-mobility and smart grids Develop mobile applications to help users find the cheapest/nearest available charging stations in the city.	Brabantstaad, Los Angeles, Goto Islands Goto Islands, Nagasaki

Developing a Local EV Action Plan	Action Plan for Electromobility Berlin 2020 set forth three main goals: 1) Improve the quality of life for the population by utilizing electromobility's potential to reduce noise and tailpipe emissions. 2) Sustainably strengthen the economy and establish new jobs for skilled workers. 3) Boost the development of new technologies and services and market them in an "international electromobility showcase PlaNYC emphasizes greening of fleet, streamlining home installations and deployment of public charging stations in planNYC	Berlin, Germany New York, USA
Urban Development Integration	Hamburg has a clear strategy for EV adoption, smart development of urban structures, environmental and climate protection, competitiveness and economic viability. This political approach also includes the implementation of e-mobility schemes in housing programs, spatial planning and district development. Charging stations on public ground have to be in line with urban layout and city architecture	Hamburg
Flexible Rental Model	People can rent the car or the battery separately. The city provides free battery rental for three years or up to 60,000 km for people who purchase E4W .	Hangzhou, China

Source: IEA (2012); Marquis et al., (2013)

Appendix B: Technology Assumptions for E2W Wheeler and E4Wheeler : BAU

Sr. No.	Technology	Unit	2015	2020	2030
1	E2W				
1a	E 2W - Lead Acid Battery				
	Capital Cost	Rs/unit	37,000	36.500	35750
	Operating Cost (excluding energy)	Rs/km	0.88	0.84	0.78
	Efficiency	km/kwh	56	58.9	65.1
	Constraint	Maximum Share limited to Urban Demand & 20% of Rest			
1b	E 2W - Lead Acid Battery				
	Capital Cost	Rs/unit	45,000	44,500	43,750
	Operating Cost (excluding energy)	Rs/km	1.32	1.26	1.17
	Efficiency	km/kwh	18.7	19.7	21.8
	Constraint	Maximum Share limited to Urban Demand & 20% of Rest			
1c	E 2W - Li Ion Battery				
	Capital Cost	Rs/unit	160,000	110,500	91,800
	Operating Cost (excluding energy)	Rs/km	2.35	1.03	0.53
	Efficiency	km/kwh	35	35	35
2	E4W				
2a	E 4W - Li Ion Battery - Small Size & DR less than 100 km				
	Capital Cost	Rs/unit	700,000	642,500	549,000
	Operating Cost (excluding energy)	Rs/km	5	3.85	1.98
	Efficiency	km/kwh	10	10	10
	Constraint	Maximum Share limited to Urban Demand & 20% of Rest			
2b	E 4W - Li Ion Battery -Medium Size & DR less than 200 km				
	Capital Cost	Rs/unit	1,728,000	1,053,000	798,000
	Operating Cost (excluding energy)	Rs/km	30	13.13	6.75
	Efficiency	km/kwh	6.7	6.8	7.1

Information about the project:

UNEP Transport Unit in Kenya, UNEP DTU Partnership in Denmark and partners in India have embarked on a new initiative to support a low carbon transport pathway in India. The three-year 2.49 million Euro project is funded under the International Climate Initiative of the German Government, and is designed in line with India's National Action Plan on Climate Change (NAPCC). This project aims to address transportation growth, development agenda and climate change issues in an integrated manner by catalyzing the development of a Transport Action Plan at national level and Low Carbon Mobility plans at cities level.

Key local partners include the Indian Institute of Management, Ahmedabad, the Indian Institute of Technology, Delhi and CEPT University, Ahmedabad. The cooperation between the Government of India, Indian institutions, UNEP, and the Government of Germany will assist in the development of a low carbon transport system and showcase best practices within India, and for other developing countries.

Homepage : www.unep.org/transport/lowcarbon

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