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PAPER

Are we set for Electric Cars?

Questioning the Environmental Readiness of India

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Abstract Electric Vehicles (EVs) have been proposed as a means to reduce the greenhouse emissions from the transportation sector. Despite the obvious benefits of zero tail pipe emissions, EVs have a wide variety of environmental effects which must be taken into calculation before a verdict can be passed on their effectively. The systems used to generate and run these EVs also play a part in determining the effect that they have on the environment and the market in which they are introduced. Studies, however, show that despite the emissions due to the electricity produced to run the EVs are still less than those due to burning fuel in Internal Combustion Engine (ICE) vehicles. These studies use a Well-to-Wheel equation to determine the efficiency of each vehicle type. We argue that this method is over optimistic, provides only a general analysis, and is inadequate to answer questions about environmental feasibility for different energy source mixes used in different countries. We perform a country specific analysis for India. Additionally we provide a forecast, according to four hypothetical energy scenarios, as to when it would be environmentally feasible for India to introduce EVs into the market. We find that EVs can be used as a means to reduce greenhouse gasses only after the year 2035 in the energy scenario where carbon prices have begun to strongly effect energy decisions.

Keywords Electric Vehicle - Greenhouse Emission
JEL Classification 032 - 033 - R48 - D12 - H23

Introduction

Emissions due to vehicles have been a growing concern for quite some time. In such

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discussions Electric Vehicles (EVs) are often put forward as a solution as they can replace the Internal Combustion Engine (ICEs) based vehicles with a zero-emission substitute. However, this claim of EVs, to provide zero-emission transport, has been questioned by the view that they are instead "elsewhere-emission" vehicles since the power to run them is generated through power-plants using coal, natural gas etc. which has substantial emissions (Gribben, 1996; Moriguchi & Terazono, 2000). This has been supported by a study in China (Huo, Zhang, Wang, Streets, & He, 2010) which finds that EVs are more polluting or have more emissions than the standard ICEs if the two are compared on a emissions per distance basis, making them environmentally in-feasible i.e. not better off than ICEs in reducing or limiting environmental emissions. There are also studies which have challenged the "elsewhere-emission" notion as a myth (Eberhard & Tarpenning, 2006). They use a "Well-to-Wheel" equation to prove that EVs and other hybrid versions of electric vehicles are more efficient and less polluting than ICEs. This approach, however, is overly optimistic as it assumes that the fuels will be burnt efficiently to produce the energy which will then drive the vehicles. In reality, fuels are not burnt efficiently and the emissions made per kWh of electricity produced varies from country to country due to the different mixes of electricity sources (polluting and non-polluting sources) and different technologies of harnessing them. The analysis then becomes a more country and technology specific analysis. It has been demonstrated that electricity from a grid with higher proportion of renewable sources of energy are a proper source for EVs if they are to be a better option than conventional vehicles (CVs) in terms of greenhouse gas (GHG) emissions.

In the present study we perform this analysis for India to answer the question ``Is India ready for Electric Cars?". As far as readiness for Electric Cars is concerned, one has to look at other factors beyond environmental feasibility as well such as, charging infrastructure, policy issues, market readiness etc. We restrict our analysis and discussion to the environmental feasibility alone. We look at the energy mix (percentage of different sources of energy) used by India and approximate the amount of emissions released per unit of energy produced. Combining these numbers with the average distance covered the EVs we compare the emissions per distance covered for both EVs and ICEs. Our analysis also includes four futuristic scenarios, as forecasted by (Shukla & Chaturvedi, 2012), to suggest the year and scenario when EVs will become environmentally feasible for the Indian context. We find that EVs become environmentally feasible only after the year 2035 and that too only in the scenario that carbon prices take effect and reduce the prices renewable energy sources and technology compared to non-renewable energy sources and technology. The following paper is organized as follows. We first present some background on EVs and their effect on the environment, followed by the Well-to-Wheel approach and comparison to the approach we use. Subsequent sections present the numerical analysis followed by discussion and conclusion.

Background

Given the growing interest in introducing EVs in the market it becomes important to ask whether the Indian market and environmental economy is prepared for it. Apart from the possible acceptance (or rejection) of the consumers, the environmental aspects must also be critically reviewed. We must ask, “Given the state of affairs, do Electric Vehicles (EVs) pose a possible solution to the environmental emissions problem that India faces?” Zero tail pipe emissions might be an attractive feature of EVs but the indirect emissions caused by them through electricity production might actually be more damaging than the emissions released by conventional combustion engine vehicles (Huo et al., 2010). The deciding factor will be the proportion of renewable sources of energy used for electricity production and the possible trends in the future (Aguirre, Eisenhardt, Lim, & Nelson, 2012; Chan, 2002; Hacker & Harthan, 2009; Huo et al., 2010). A higher proportion of renewables reduces the emissions released per kWh produced. We first present the manner in which energy source composition plays a part in determining the change in emissions status due to EV introduction. Next, we use four scenario projections to show when such an introduction will work towards reducing emissions. Before we begin with the said analysis we look at the Well-to-wheel equation and compare our approach to it.

The Well-to-Wheel Equation

The Well-to-Wheel equation takes into calculation the carbon content of the fuel and assumes perfect combustion to convert the carbon content to CO2 (Eberhard & Tarpenning, 2006). Using this equation the following is used:

$$W2W = \eta W2V * \eta V2W$$

Where:

$\eta W2V$ is the well-to-vehicle performance measured in %

$\eta V2W$ is the vehicle-to-wheel performance measure in km/kWh

There are a number of studies which use this equation (Stefano, Manzolini, & Iglesia, 2009) and find that EVs are more efficient than ICEs. The main drawback of this method, and possibly the reason for the conclusion they reach, is that they assume perfect combustion. Given the different grades of technologies used by different countries, the amount of energy extracted from the fuel and the emissions made will vary from technology to technology and therefore country to country. This is the reason why the W2W equation cannot be used as a measure to decide whether a country (or a system using a particular energy source of technology) will have the same environmental feasibility as another country when applying EVs as a measure to reduce environmental emissions from automobiles. Countries not only have different mixes of energy sources but also differ in the technology they use to burn these fuels, making it imperative to bring these factors into our calculations. Our approach looks at empirical data collected from the power stations as to the amounts of emissions they produce, interact it with the current energy mix of the country and then calculate the amount of emissions produced per kWh. This makes the calculation more country specific and gives a more accurate picture of the situation.

Our Approach: An Energy-mix Specific Analysis

With the onset of smart grids, there is no longer a reason to separately analyze the different grids of India. Smart grids are able to integrate the different grids together and thus a single analysis for the whole country is sufficient. We first calculate the average grams of CO_2 produced per kWh for a given mix of energy sources using the following equation:

$$\text{Co2 (gms)/kWh} = \sum_{i=1}^{n} M_1 . f_i$$

Where:
fi is the approximate CO2 (in gms) emitted by the ith fuel calculated from empirical records.
Mi is the percentage share of the ith fuel has in the energy mix of the system.

Tables 1 and 2 present the basic calculations involved in this process.

Table 1 CO2 emissions from different technologies

	g/kWh[4]
Coal	2093
Gas	473.5
Oil	627
Nuclear	0
Biomass	582
Hydro	0
Wind	0
Solar	0

Table 2 Average usage of vehicle form

Vehicle type	Passenger avg.	kWh/100Km	CO2/100Km
Electric Bike[5]	1.5	1.4	
Scooter/Bike[6]	1.5		3666.67
Hybrid car	2.5	5.9 + fuel	
Car	2.5		6400
Bus	50		2550
BEV	2	10.47	

[5] From (Cherry, Weinert, & Xinmiao, 2009); [6] Data for average usage of cars, busses, and hybrid from (Helms, Pehnt, Lambrecht, & Liebich, 2010)

Forecasting the future

Given the low penetration of electricity in India, there will be a continued increase in the demand for energy generation in the coming few decades. The rising concerns for carbon emission cuts has forced the governing bodies to re-think the manner in which future energy requirements have to be met. Coal has been the predominant source of power generation in India. Though available in larger quantities in India, it is a highly pollution fuel. Other alternatives such as hydro, solar, wind and nuclear, have only seen marginal growth in terms of percentage of total energy source composition (Shukla, Dhar, & Mahapatra, 2008). Low carbon and clean energy policies have been suggested as a means to remedy the situation. There has been an increased effort to bolster the solar and nuclear power generation technology adoption and implementation. Other technologies which can aid in this pursuit are emission reduction systems such as Carbon Capture and Storage (CCS) (Shukla et al., 2008). This technology, albeit expensive, can have a tremendous effect on reducing global and regional carbon emissions. In the paper titled ``Low carbon and clean energy scenarios for India: Analysis of targets approach'' (Shukla & Chaturvedi, 2012), four future scenarios are projected, each emphasizing on a different source of reduction of emissions. The four scenarios are:

- Business As Usual (BAU) Scenario with no carbon price or electricity targets (BAU-noT with reference nuclear cost)
- BAU Scenario with no carbon price or electricity targets but increased nuclear cost (BAU-noT with increased nuclear cost)
- Carbon Price Scenario with exogenously specified carbon price trajectory but no electricity targets (CP-noT with reference nuclear cost)
- Carbon Price Scenario with exogenously specified carbon price trajectory and increased nuclear cost (CP-noT with increased nuclear cost)

Each of these scenarios gives a different picture of changing energy source compositions over the years from 2005 to 2095. We borrow the different percentage compositions of energy sources from these projections to demonstrate the performance of different EVs vis-à-vis conventional vehicles. Before we proceed with these projections a brief introduction and explanation of these scenarios is necessary.

BAU scenario with and without increased nuclear cost. BAU- Business as Usual approach assumes an average GDP of 8% in the short run and 5% in the long run. In this scenario different renewable energy targets will only be achieved through subsidy push. Coal will continue to take the highest share in the country. Nuclear technology, solar technology and other more expensive technologies are to enter into the market very late. Carbon price scenario with and without increased nuclear costs. This scenario assumes an automatic shift towards low carbon emission technologies and energy sources. Since there is a carbon price effect on this scenario, renewable energies will see a much early entry into the market and will see a higher share in the energy source pie.

In both the cases the sensitivity to nuclear prices makes a difference. In the `increased nuclear cost' scenarios the discounted lifetime costs of implementing stronger nuclear safety mechanisms, which is assumed to be 50% of non-energy related nuclear cost, increases the cost of adopting nuclear technologies and thus pushes down the percentage share of nuclear electricity generation. The following are the different percentage compositions of energy sources in the four different scenarios: Figure 1a, Figure 1b, Figure 1c and Figure 1d

Figure 1a BAU-noT with reference nuclear cost (Adopted from Shukla and Chaturvedi, 2012)

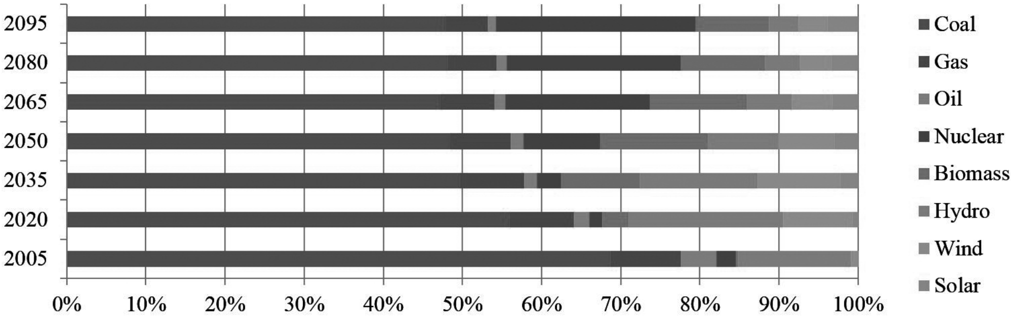


Figure 1b BAU-noT with increased nuclear cost (Adopted from Shukla and Chaturvedi, 2012)

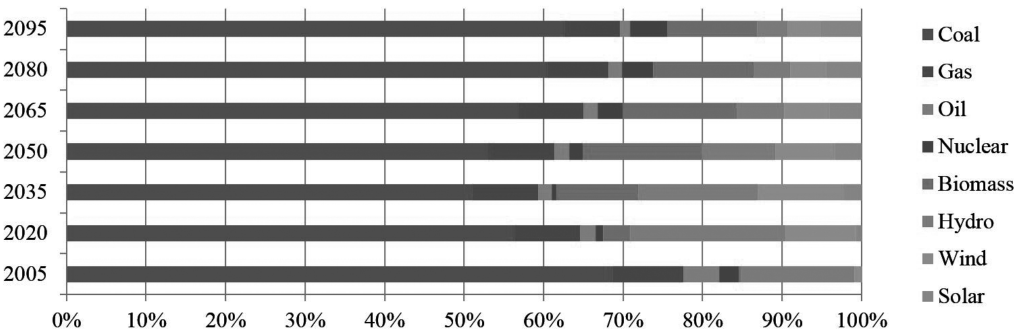


Figure 1c CP-noT with reference nuclear cost (Adopted from Shukla and Chaturvedi, 2012)

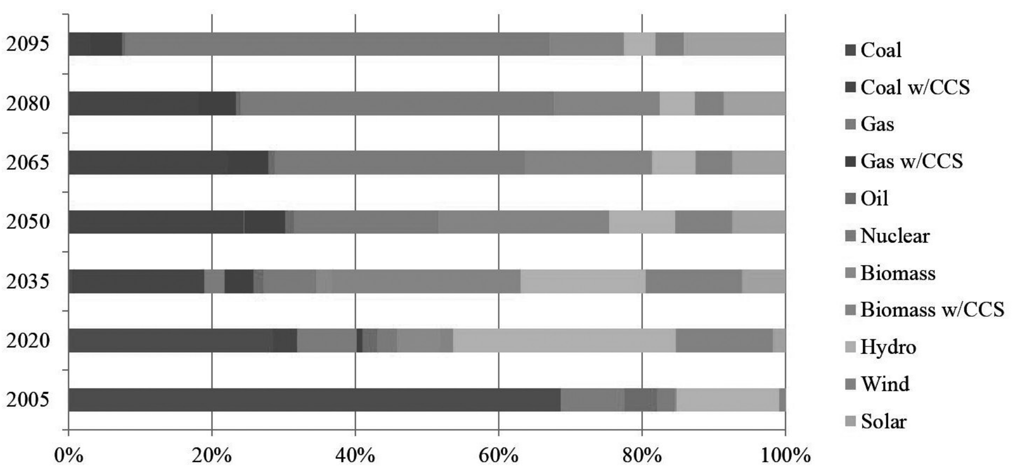
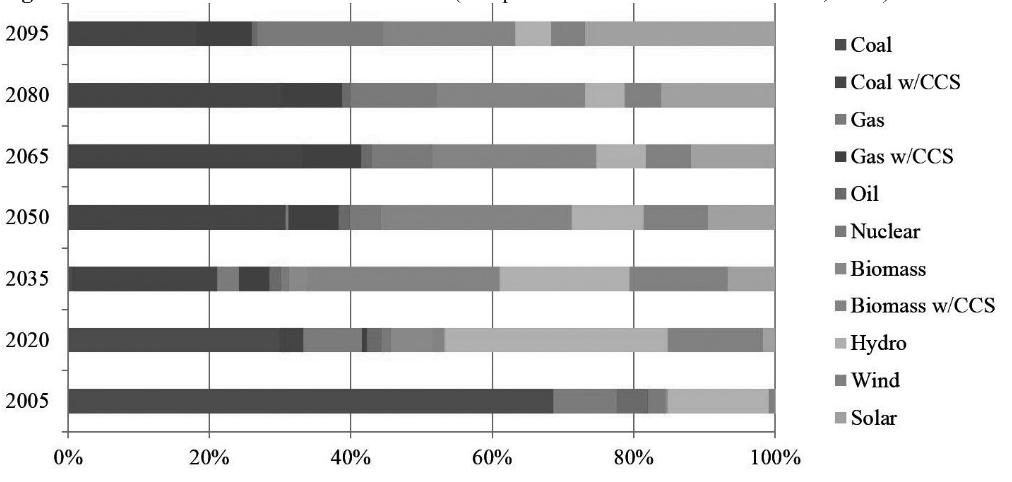


Figure 1d CP-noT with increased nuclear cost (Adopted from Shukla and Chaturvedi, 2012)



The Figures 1a to 1d show the four scenarios and the different energy mix expected in the years to come within each scenario. As can be expected the latter two Figures show a decrease in the percentage of non-renewable energy sources. The reason for this is that the scenarios describe a situation where carbon prices have taken hold and made renewable sources more accessible. This is expected to change the emissions mix and environmental feasibility of EVs as shown in the subsequent sections.

Numerical Analysis

According to these percentage compositions the ‘per kWh’ emissions from EVs will change over the years. It gives us an opportunity to judge at which year and in which scenario we can safely replace conventional combustion engine vehicles with EVs.

The Figures 2a, 2b, 2c and 2d show the CO2/100 Kms for the different vehicles over the years for the four different scenarios. According to these percentage compositions the ‘per kWh’ emissions from EVs will change over the years. It gives us an opportunity to judge at which year and in which scenario we can safely replace conventional combustion engine vehicles with EVs.

Figure 2a BAU -not with reference nuclear cost (Adopted from Shukla and Chaturvedi, 2012)

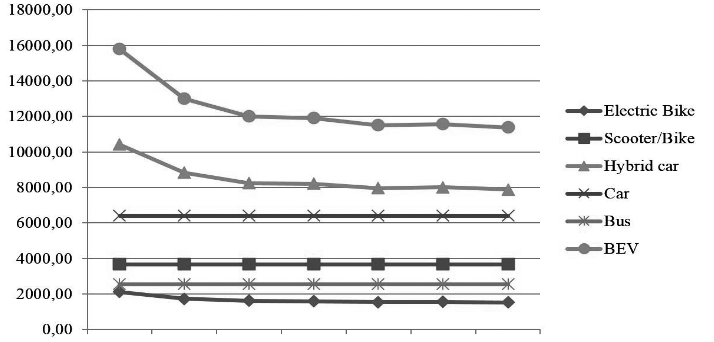


Figure 2b BAU -not with increased nuclear cost (Adopted from Shukla and Chaturvedi, 2012)

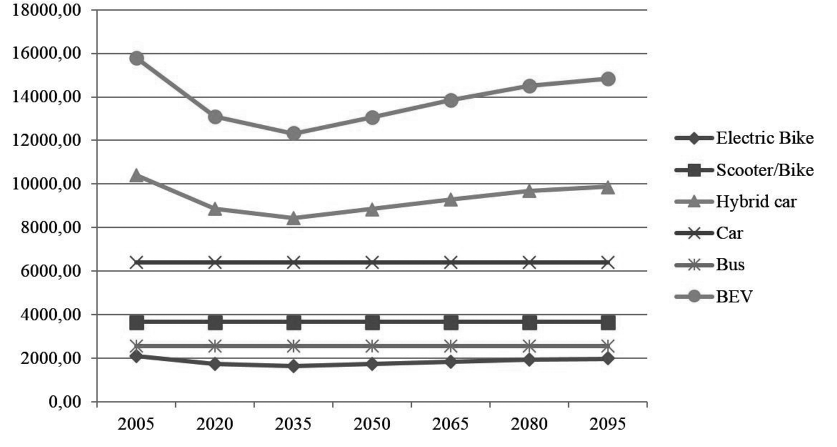


Figure 2c CP-noT with reference nuclear cost (Adopted from Shukla and Chaturvedi, 2012)

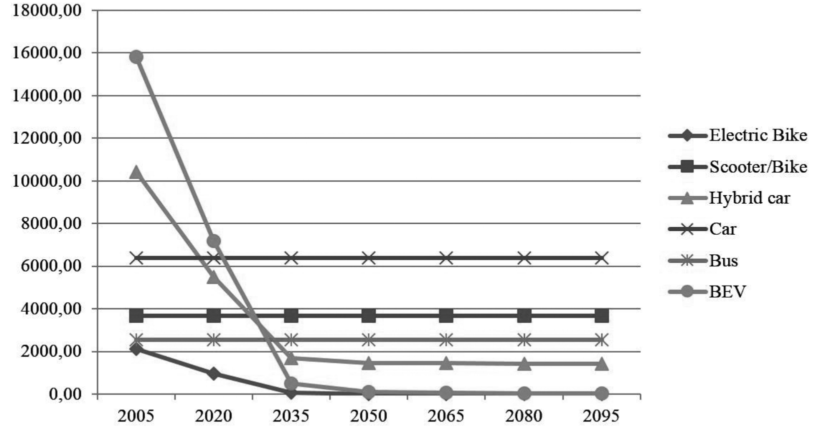
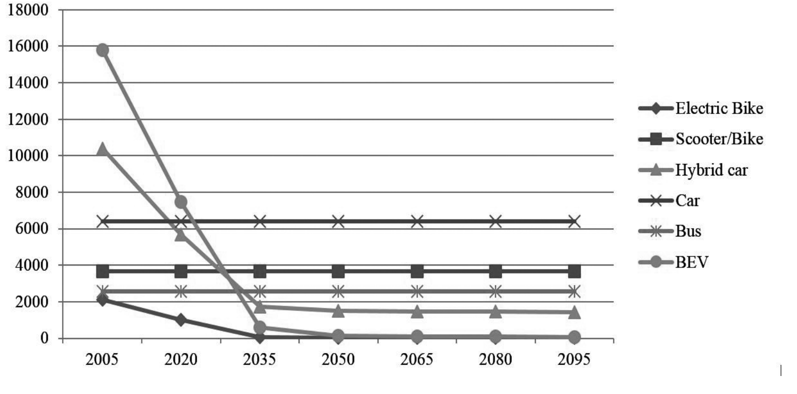


Figure 2d CP-noT with increased nuclear cost (Adopted from Shukla and Chaturvedi, 2012)



As can be seen from Figures 2a to 2d, it is clear that the scenario changes drastically for the latter two cases. When Carbon prices take effect the prices of renewable sources and technologies become cheaper, as compared to non-renewable energy sources and technologies, and therefore more accessible. This changes the amount of emission produced per kWh and therefore the emissions per distance covered for the EVs. Thus, after 2035 it is expected that the energy mix will change sufficiently to make EVs more environmentally feasible than ICEs. An interesting observation is that in all four scenarios and throughout the predicted time period electric bikes show as a viable option. This is also supported by the fact that they are immensely popular in China which has a similar (coal intensive) energy mix usage as India, and similar population density. It goes on to show that even if the energy mix is a problem for four wheeled EVs, two wheeled electric bikes are an environmentally feasible option and the Indian system is read for their introduction.

To summarize, the graphs show the per-passenger CO2 emitted per 100 Km by each type of vehicle . It suggests that Electric bikes are already a better alternative than most of the vehicles and remains so in the coming years. They have proven to a successful alternative to public transport such as busses. The analysis is sound since it compares the per person emission thus taking into account the higher carrying capacities of busses. Therefore we argue that:

Proposition 1: From the CO2 emissions point of view India is environmentally ready for introduction of Electric bikes.

Battery operated vehicles (BEVs) and Hybrid Electric Vehicles (HEVs) on the other hand are shown as more polluting through the projection period in the first two scenarios. This suggests that even though energy source compositions changing for the better, more renewables, the change will not be enough to make BEVs and HEVs a better option, pollution wise, compared to the conventional vehicles. Scenario 2 actually shows an upward swing due to increase in nuclear energy costs and therefore a lesser proportion of this non-greenhouse producing source. Therefore we argue that:

Proposition 2: BEVs and HEVs will not be well suited as greenhouse emission reducing options as long as carbon prices do not play a large role in the energy economics of the country.

The analysis changes in the latter two scenarios. Due to a carbon-price scenario the fuel prices for greenhouse producing options increase and make other renewable sources cheaper. This condition pushes the projection towards a higher proportion of renewable energy sources and therefore decreases the CO2 emissions per kWh. As is clear from Figure 2c and 2d (Carbon prices scenario) running BEVs and HEVs becomes more environmental around the year 2035. The change might appear in the preceding years but the model definitively speaks for 2035. It also shows that BEVs will be more non-polluting efficient than the HEVs. Therefore, we argue that:

Proposition 3: In case of carbon prices playing a larger role in energy economics of India BEVs will emerge as the dominant greenhouse reducing options among, Electric Bikes, HEVs and BEVs.

The above analysis is done only on the basis of CO2. Since the proportions of emissions for other greenhouse gasses such as NOx, SO2 etc. are not very different for the different vehicle types; the analysis for these gasses is expected to give almost the same results.

Conclusion

To conclude we first reiterate the main findings of the study. We find that the present energy source mix used by the Indian power sector does not support the use of EVs as an environmentally feasible option. We still need to reach a position where the energy mix will provide a cleaner power output, which in turn will be a better substitute for the fossil fuels we burn in our automobiles. Another interesting finding from the study is that this condition only occurs in the latter two scenarios: CP-noT with reference nuclear cost and CP-noT with increased nuclear cost. It suggests that if Carbon prices do not come into effect, it might never be feasible to introduce EVs into the Indian system. This statement appears too bold and we suggest caution when stating it ourselves, but the analysis points towards this direction. What can be safely inferred is that unless carbon prices take effect and cleaner fuels become more viable, introducing EVs will continue to be a difficult prospect.

We make quite an audacious attempt by estimating the future of EVs in India for the next hundred years, and we could not have done this without making some rather hard assumptions. These assumptions in themselves limit the generalization of our results and give reason to be circumspect of our conclusions. For one, we assume that the technology will not improve over the years. This can be challenged. Technological improvements over the years might make EV technology more advanced and quicken the time required for them to become equivalent or better substitutes of the ICEs. However, ICE technology is also expected to improve so they will compete for being the better alternative. Thus, we assume that these two factors will more or less cancel each other out. Another challenge can be that both renewable and non-renewable source technology will change over the years. For this we depend on the predictions, assumptions and controls adopted by (Shukla & Chaturvedi, 2012). We also make large approximations; average values for different power sources were averages over different power plants and over many years. We however feel they will not shake our results to any significant degree. Another limitation is that the data for vehicles was taken from multiple sources. Since we did not have data for average distance covered per unit fuel, or CO2 per km for all the vehicles in the India context, we borrow heavily from other studies dealing with this issue. This can again affect the results but again we suspect it would not do so to a significant degree.

We hope that future studies are able to overcome some of these difficulties. Also, our study was restricted to only CO2. Future studies can look at other green-house gases as well.

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Appendix 1

BAU -not with reference nuclear cost							CO2 gm/100 Km			
Passenger avg.	Vehicle type	kWh/100Km	CO2/100Km	2005	2020	2035	2050	2065	2080	2095
1.5	Electric Bike	1.4		2112.54	1737.60	1603.48	1593.12	1539.38	1548.05	1522.39
1.5	Scooter/Bike		3666.67	3666.67	3666.67	3666.67	3666.67	3666.67	3666.67	3666.67
2.5	Hybrid car	5.9 + fuel		10409.49	8813.31	8242.33	8198.23	7969.43	8006.35	7897.14
2.5	Car		6400	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00
50	Bus		2550	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00
2	BEV	10.47		15798.80	12994.77	11991.73	11914.26	11512.33	11577.18	11385.34
BAU -not with increased nuclear cost							CO2 gm/100 Km			
Passenger avg.	Vehicle type	kWh/100Km	CO2/100Km	2005	2020	2035	2050	2065	2080	2095
1.5	Electric Bike	1.4		2112.54	1749.92	1648.17	1746.22	1851.61	1940.47	1984.88
1.5	Scooter/Bike		3666.67	3666.67	3666.67	3666.67	3666.67	3666.67	3666.67	3666.67
2.5	Hybrid car	5.9 + fuel		10409.49	8865.75	8432.58	8850.00	9298.66	9676.94	9865.99
2.5	Car		6400	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00
50	Bus		2550	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00
2	BEV	10.47		15798.80	13086.89	12325.94	13059.23	13847.40	14511.93	14844.03
CP-noT with reference nuclear cost							CO2 gm/100 Km			
Passenger avg.	Vehicle type	kWh/100Km	CO2/100Km	2005	2020	2035	2050	2065	2080	2095
1.5	Electric Bike	1.4		2112.54	959.44	65.73	11.83	7.39	4.98	3.82
1.5	Scooter/Bike		3666.67	3666.67	3666.67	3666.67	3666.67	3666.67	3666.67	3666.67
2.5	Hybrid car	5.9 + fuel		10409.49	5500.55	1695.92	1466.46	1447.55	1437.30	1432.34
2.5	Car		6400	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00
50	Bus		2550	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00
2	BEV	10.47		15798.80	7175.21	491.58	88.49	55.26	37.25	28.54
CP-noT with increased nuclear cost							CO2 gm/100 Km			
Passenger avg.	Vehicle type	kWh/100Km	CO2/100Km	2005	2020	2035	2050	2065	2080	2095
1.5	Electric Bike	1.4		2112.5431	999.53853	77.601047	17.169636	13.328509	10.670115	7.1576384
1.5	Scooter/Bike		3666.666667	3666.6667	3666.6667	3666.6667	3666.6667	3666.6667	3666.6667	3666.6667