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Environmental and Economic effects of introducing Japanese Eco-Cars into Indian market

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Abstract

With an increasing economic growth in India, harmful environmental effects such as emissions come into the picture, out of which automobile sector contributes to a major percentage. There is a need for reduction in vehicular emissions with increasing demand in 4-wheeler passenger vehicles. A major step towards reducing emissions is introducing Electric Vehicles and Hybrid Electric Vehicles. With rapid rising fuel prices in India, this future direction of automobiles is more sought. The performance of these vehicles depends on the diving behaviour and vehicle drive train configuration and the driving behavior in turn depends on factors such as road infrastructure, traffic conditions and driver mentality. All commercial vehicles are designed considering several factors such as vehicle operating range, accelerations, decelerations, maximum speed, power output at various stages and factors as such which are directly represented by a driving pattern. Hence a driving pattern is necessary to design the components for a HEV. A driving pattern was constructed based on actual speed-time data collected from diverse cities in India. Japanese automobile industry being one of the leading manufacturers of EVs and HEVs and owning a considerable portion of automobile market in India could possibly help in introducing HEVs into India. Hence different HEVs, Gasoline and Diesel cars were tested on this driving pattern to accumulate data pertaining to designing process.

Keywords: Electric Vehicle, Hybrid Electric Vehicle, Emissions, Environment, India

1 Introduction

One major cause for CO_2 emission is road transport which is emerging as the largest source relating to the rapidly increasing number of vehicles and relaxed emission control strategies. Excessive emissions from this sector and ever rising fuel costs have constrained the major direction to shift towards cleaner vehicles such as EV and HEV. Major research in HEV deals with an effective and low cost drive system that results in lower emission and higher fuel economy. However efficient the drive system might be, the overall results depend on the traffic, road infrastructure and driving behaviour of a particular country. HEV design for a specific country is based on its standard driving cycle, however international car makers do not alter the design or each country much in order to keep the production cost low. A driving cycle is a speed-time curve representing vehicle operating conditions such as idling, acceleration, deceleration, cruising pertaining to a particular city, state or country. These driving cycles are usually of two types, synthetic and actual.

Synthetic driving cycles, such as the European and Indian driving cycles are constructed based on constant acceleration, deceleration and cruising speed and result in a non-real driving behaviour. These type of driving cycles serve the lone purpose of evaluating emissions and fuel economy for control strategies and catalogue rating respectively, however it does not serve the purpose of designing vehicles. On the other hand, actual driving cycles such as JC08 for Japan represent the traffic behavior much precisely with variable cruising speeds and non-constant accelerations and decelerations. These patterns particularly have variable acceleration, cruising speeds and decelerations which precisely represent actual driving conditions in a region.

India has been an active target for many automobile manufacturers from the past decade. Modified Indian Driving Cycle (MIDC) was formulated in 2000 by the Automobile Research Association of India(ARAI) to measure the fuel consumption. MIDC was formulated based on the New European Driving Cycle by limiting the maximum speed to 60 km/h instead of the 90 km/h for the European case [1].NEDC being a synthetic driving cycle does not represent actual European driving characteristics precisely, and adopting it for the Indian case is in-appropriate as the European driving behavior, the infrastructure and traffic rules are extremely different from the Indian situation. Construction of a New Real Time Indian Driving Cycle (named XD) was done for the estimation of fuel economy and emission for vehicles on Indian driving condition.

To study how CO_2 emissions can be controlled in long term by introducing EVs and HEVs into India is important to decide the quickest and most efficient route to it, taking into account the cost. This however needs the vehicles to be driven on Indian roads or formulating a driving cycle to do that. Designing of HEV equally demands a driving cycle so as to size it's components for minimum emission and cost along with maximum efficiency. The major factors derived from the driving cycle that effect the design of HEV are the power required for acceleration and cruising, power regenerated during deceleration, peak power demand, sharp emissions in high traffic driving etc.,

The research is divided into two major parts. One being construction of the driving cycle for India and second being testing standard cars and HEVs on this cycle to study the specific behavior at different driving conditions and analyzing a long term emission and economic outcome.

2 Procedure

2.1 Construction of XD (Real Time Indian Driving Cycle)

A driving cycle was developed for Indian driving condition based on real time driving data from in and around four major Indian cities that are expected to precisely represent the driving behavior of the India. 25 hours of streaming speed-time data was obtained from these cities under different conditions ranging from time of the day to day of the week including specific weekend conditions. The construction of this driving cycle consists of two stages, (i) Collection of driving data, from different cities under different conditions (ii) Processing data based on a unique algorithm., (iii) Validating the constructed driving cycle using commercially available cars in Indian market on chassis dynamometer.

(i) Data Collection: Four cities namely Delhi, Mumbai, Pune and Bangalore were chosen to conduct driving experiments to obtain the speed-time data required for constructing the driving cycle. These four cities were assumed to represent the overall Indian driving situation as they contribute diversity in driver behavior, infrastructure and traffic. A commercial Indian hatchback car was chosen and fitted with simple data acquisition system coupled to the cars odometer. A random car was chosen from specific points and followed until their destination at a constant distance of 2 meters measured by a proximity sensor. This was done on different cars for different time periods, peak hours and non-peak hours, weekdays and weekends, busy roads and suburbs, city and highway etc.,

(ii) Data processing: Firstly, the raw data was processed to eliminate errors resulting in the variation of the constant 2 meter distance. Points where the distance between casual car and the data acquisition car exceeded or fell short of the 2 meter threshold were refined based on the instantaneous changes. A special and unique algorithm was developed to process several hours of the refined driving data to construct the new driving cycle.

The refined raw data was then divided into several microtrips, where a microtrip is the speed-time curve in between two idling positions. These microtrips were then segregated into groups based on factors like average acceleration, average deceleration, average speed, maximum acceleration, maximum deceleration, maximum speed, minimum acceleration, minimum deceleration, minimum speed, and most specifically higher differentials of speed which uniquely represent the traffic driving, urban driving and highway driving characteristics.

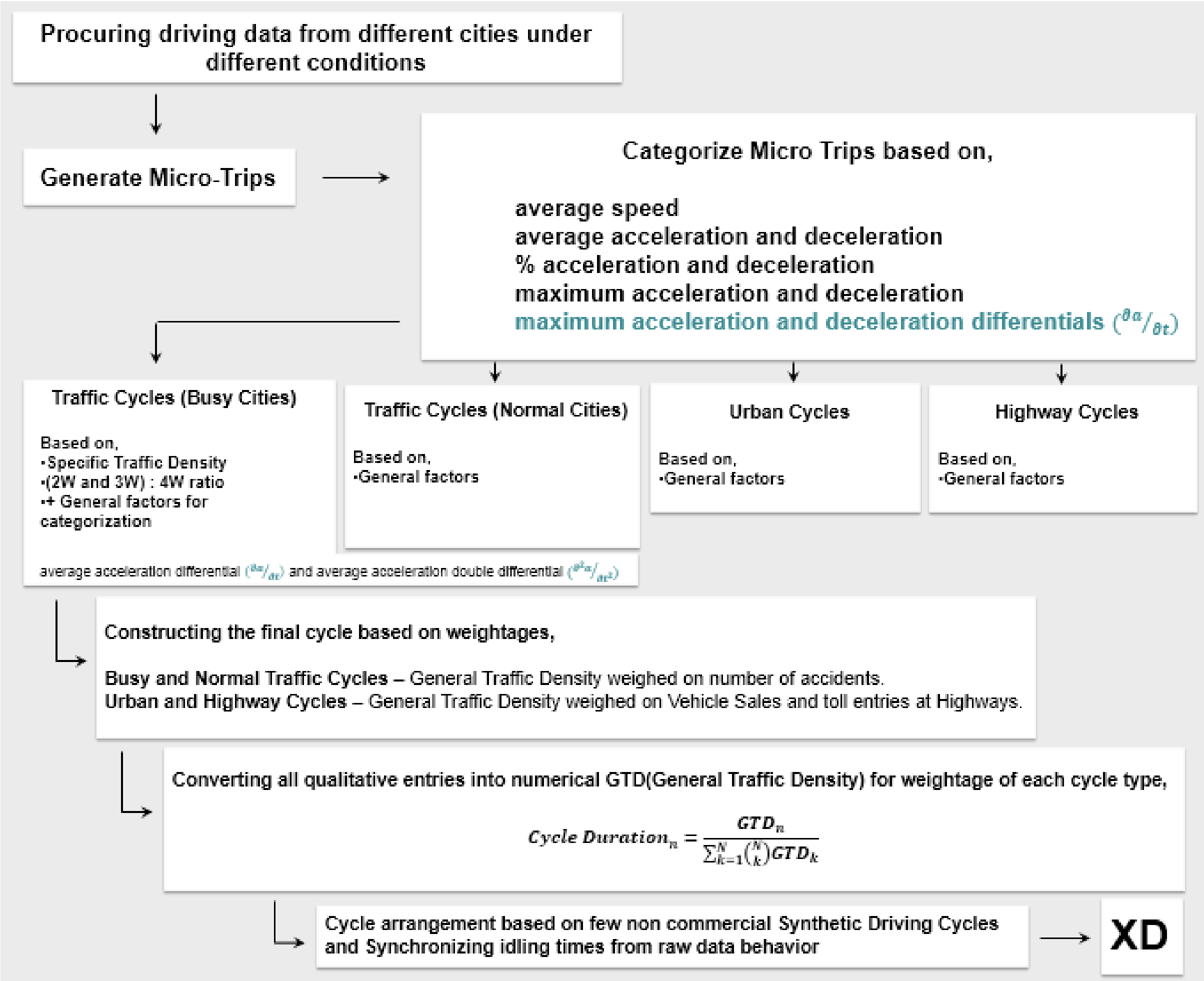

Figure 1: Algorithm for construction of XD

Several microtrips from each groups that represent unique driving condition were then selected based on maximum occurrences to construct the final driving cycle, XD.

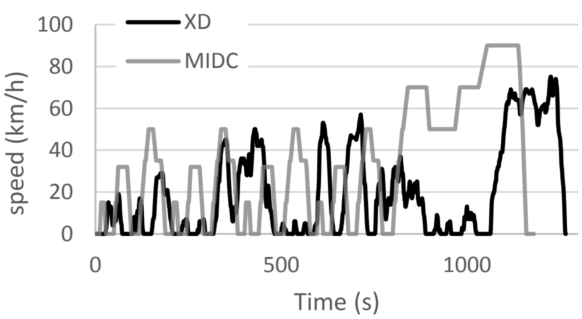

Figure 2: A comparison of XD(Red) against MIDC

Unique feature of this driving cycle is its traffic portions which precisely represent the Indian driving conditions and are characterized by low speeds, high acceleration and high deceleration in short intervals of time. These traffic portions make all the difference in fuel economy, emissions, regenerative braking power and many other important factors. One such traffic portion is shown below.

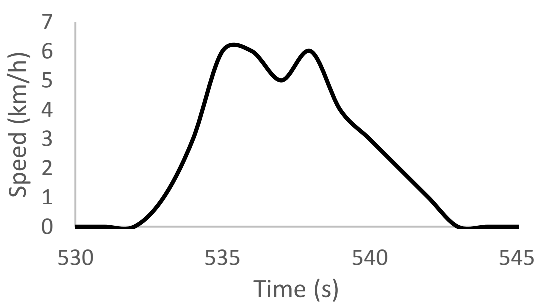

Figure 3: A traffic portion from XD

This traffic portion shows a peak speed of 6 km/h with a maximum instantaneous acceleration of 3 km/hs, and a maximum deceleration of 2 km/hs in a span of 11 seconds. Such extreme driving conditions are usually absent in developed countries like Europe and hence their synthetic driving cycle for emission control, cataloguing and designing of vehicles is not feasible in India. This algorithm takes into consideration new factors of higher differentials of speed to study the relation between the fluctuations in acceleration to the final performance of the vehicle. Two such factors in this study are the differential of acceleration and double differential of acceleration which were chosen to be a major criteria in segregation of microtrips. This factor was taken in consideration based on experimental observations of the relation between these factors and the CO_2 flux emission at a point.

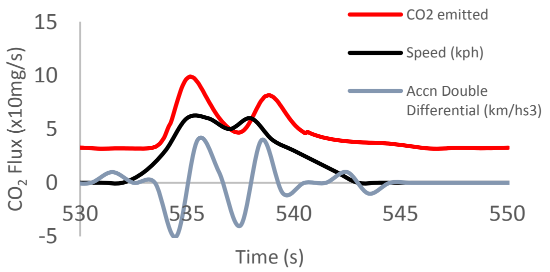

Figure 4: CO_2 emission in a typical Indian traffic driving

Figure 4 shows the CO_2 flux emitted (red) against the speed (black) and double differential of acceleration (blue). This observation shows that the CO_2 flux emitted minimally depends on the speed and maximally depends on its higher differentials. In this case the top speed was 5km/hr and the CO_2 flux peaked at 0.1 g/s. It shows that the CO_2 flux emitted at a point has a close relation to the Double differential of acceleration and follows a similar trend after a critical speed. At lower speeds, the dependence is not distinct, however when the speed crosses a threshold value (in this case of an Indian gasoline car under experiment, the threshold speed being around 4 km/h) the change in CO_2 flux emitted is found to be directly in consistence with the changes in double differential of acceleration at that point. A special run on a MIDC portion with high speed and lower acceleration differentials and lower higher differentials were carried out and the CO_2 flux results analysed.

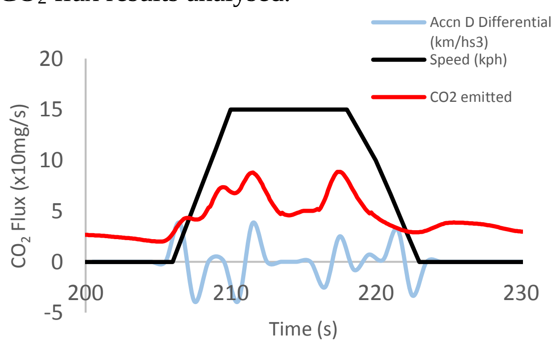

Figure 5: CO_2 emission with MIDC

This figure again shows the dependence of CO_2 flux on the higher differentials of acceleration/velocity rather than on the speed. The top speed in this case is 15 km/h, which is much higher compared to the 5 km/h of the previous XD traffic driving portion but the CO_2 emission flux here peaked at 0.08 g/s compared to the 0.1 g/s of the XD case. This is a clear indication that the CO_2 emission massively depends on the higher differentials of speed and acceleration along with a minimal dependence on the speed.

Several of such situations were taken into consideration along with behaviour of diesel version of the same vehicle. The diesel vehicle's CO_2 emission flux being dependent on the second differential of acceleration further validates the relation, however the threshold speed seems to vary from the gasoline vehicle results. These higher differentials majorly describe how poorly the engine is handled and the chaotic speed control characteristics. Greater values of higher differentials means higher speed and acceleration fluctuations. Hence higher differentials of speed/acceleration to group the micro-trips contributes to a unique part in construction of the XD driving cycle.

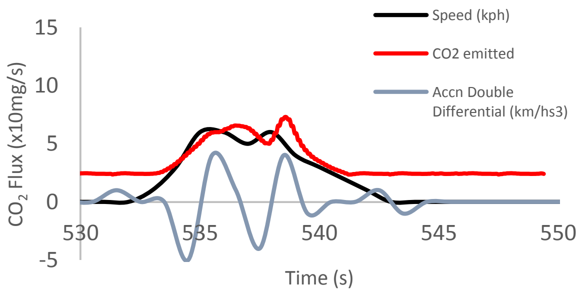

Figure 6: CO_2 emission in a typical Indian traffic driving (Diesel Vehicle)

The fuel economy and performance is also expected to be directly dependent on these higher differentials. Higher differentials of accelerations are a major characteristic feature of Indian city driving and eventually a major factor to be considered in designing of vehicles for India. In the particular Indian driving case, the major weightage in design must be on the ultra-capacitors rather than the battery itself for the short duration, vigorous driving.

(iii) Validating the Driving Cycle: The validation of the driving cycle was carried out driving gasoline and diesel models of a commercial Indian 4 wheeler passenger vehicle on chassis dynamometer using the developed driving cycle and the Fuel economy was compared against real time on road fuel economy data collected from various users and driving experiments conducted in India. Table 1 shows the

Fuel economy data from XD compared against actual on road fuel economy and the catalogue values/MIDC values.

Car	Commercial Indian Car	Commercial Indian Car
Type	Gasoline	Diesel
Catalogue Fuel Economy	18.6 km/l	22.4 km/l
MIDC Fuel Economy	18.83 km/l	23.16 km/l
XD Fuel Economy	14.47 km/l	18.91 km/l
On Road Fuel Economy	14.22 km/l	18.86 km/l

Table 1: Validation of XD

These values are comparable to those of the actual values which can conclude that the driving cycle is valid enough for the intended purpose and also provides a good standard for further research in any field related to automobile performance in India.

3 Experimental setup

3.1 Commercial 4-wheeler passenger Vehicles

Four vehicles in total, a commercial gasoline ICE vehicle in Indian market (Car A), a commercial Diesel vehicle in Indian market (Car B), a commercial Hybrid Electric Vehicle (HEV) in Japanese market (Car C) and a commercial Plugin Hybrid Electric Vehicle (PHEV) in Japanese market (Car D) were selected for this study. Car C was chosen based on being the largest selling Eco car in the Japanese market as well as numerous western markets, hence we assume that the first step of Indian introduction to eco cars could be the same, with a slightest variation if so. Car D is chosen due to a similar background reason of it being almost the same car designed into a Plugin Hybrid Electric Vehicle and also the largest selling in its category in Japan and other western countries. These four cars were tested on XD driving cycle on a chassis dynamometer coupling several data acquisition systems. The major systems in the experiment are the Constant Volume Sampler for analyzing Exhaust gas and the Roller Data Acquisition system for analysing the dynamic variables of the vehicle like traction force etc., along with the fuel economy and engine performance. Specifications of the vehicles in this study are given in the following four tables.

Car A	Commercial Indian Vehicle
Type	Gasoline
Engine Capacity	1.2 L

Table 2: Specification of Car A

Car B	Commercial Indian Vehicle
Type	Diesel
Engine Capacity	1.4 L

Table 3: Specification of Car B

Car C	Commercial Japanese Vehicle
Type	Hybrid
Engine Capacity	1.8 L
Battery Capacity	1.3 kWh

Table 4: Specification of Car C

Car D	Commercial Japanese Vehicle
Type	Plugin Hybrid
Engine Capacity	1.8 L
Battery Capacity	4.4 kWh

Table 5: Specification of Car D

3.2 Test Procedures on the different vehicles

The basic vehicle performances, such as fuel consumption and CO_2 emissions, of the test vehicles were measured in order to observe their variation in usage on Indian driving conditions. The test vehicles were tested with XD Driving Cycle under different initial conditions. The Gasoline, Diesel and HEV were driven on XD in cold and hot conditions and the PHEV was cyclically driven from a fully charged condition to charge sustaining mode and finally in HEV mode.

4 Experimental results

Major areas of interest in HEVs in Indian market are its emissions, cost, fuel economy and more specifically, the performance under characteristic high acceleration, low speed and high deceleration short duration traffic drives of the Indian Driving pattern. The study on this specific feature of the Indian driving behaviour is absolutely necessary in designing the drive train, components like motors, batteries, ultra-capacitors etc.,. These short duration traffic portions of the XD driving cycles are expected to be using high amounts of energy, but the equally vigorous decelerations are expected to generate energy. Components and drive train system must be designed as such to contribute the necessary energy burst required for the high accelerations to take complete advantage of the immediate sharp decelerations.

4.1 CO_2 Emissions

From the test results, the CO_2 emission against drive length was estimated. The results are shown in figure x. 6.5 tons in case of Gasoline vehicle, X tons in case of Diesel Vehicle, Y tons in case of HEV was estimated as the amount of CO_2 emission which the vehicle emits during the drive for 40 km. The CO_2 emission values were experimentally determined in case of Car A, Car B and Car C. In case of Car D (PHEV), the CO_2 from electric drive and HEV mode drive were separately estimated. The CO_2 from electric drive was calculated using the CO_2 coefficient for electricity generation in India in the 2009 fiscal year[2] valued at 960 g/kWh, while the HEV mode got its CO_2 value from the experimental data.

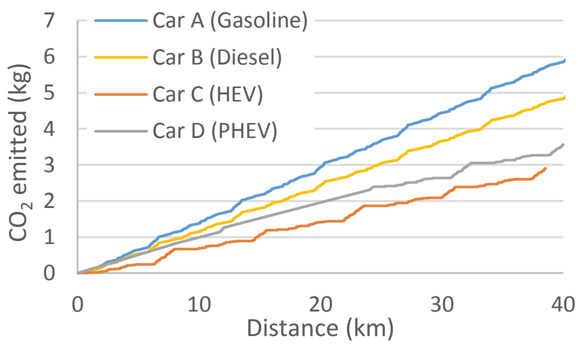

Figure 7: CO_2 emitted per day (40 km)

This figure shows the CO_2 emitted from the four different cars on Indian Driving conditions. The CO_2 emission represented here is for a range of 40 km which is assumed to be the average distance traversed by a passenger vehicle per day in India [3]. The table below shows the CO_2 emitted per km of each of the cars.

Vehicle	CO2 emitted per km
Car A (Gasoline)	147.29 g/km
Car B (Diesel)	121.69 g/km
Car C (HEV)	72.19 g/km
Car D (PHEV)	91.39 g/km

Table 6: CO_2 emission on XD Driving Cycle

4.2 Fuel Economy

The fuel consumption in each of the four vehicles, all on the real time driving cycle (XD), were measured. In case of Car D (PHEV), the electric energy consumption and electric range were routinely measured till it started running on HEV mode. On HEV mode the fuel consumption was experimentally obtained from the chassis dynamometer data acquisition system. In case of Car A, Car B and Car C, the fuel consumption was obtained similarly.

These experiments were conducted under different conditions such as cold start, where the car is kept off over night and the experiment begins with no prior engine heating, and hot start which was done after the cold start series when the engine is heated up. These experiment results were then averaged for optimum results.

Vehicle	Electric Range	Fuel Economy
Car A (Gasoline)	-	14.47 km/l
Car B (Diesel)	-	18.91 km/l
Car C (HEV)	-	28.64 km/l
Car D (PHEV)	24.5 km	29.17 km/l

Table 7: Fuel Economy on XD Driving Cycle

Table 7 shows the fuel economy values of the four vehicles along with the electric range of Car D.

5 Discussion

5.1 CO_2 emission on Indian Driving Behaviour

The results of CO_2 emissions were as predicted, however the comparison of CO_2 emission in case of HEV and PHEV are of interest. PHEVs are designed as an optimum solution for a better fuel economy and lower CO_2 emissions in case of developed countries, but in case of the Indian driving behaviour and its limited clean energy generation sources, the PHEV and EVs do not contribute to CO_2 reduction compared to already existing Diesel vehicles in Indian market. In this study, the CO_2 emission in the usage stage is more concentrated upon. However a simple analysis of CO_2 generation in production of the PHEV in study based on the Japanese standards for the same vehicle suggest a non-profitable CO_2 reduction. Taking battery replacement in PHEVs due to their degradation into consideration could result in a much higher CO_2 emissions.

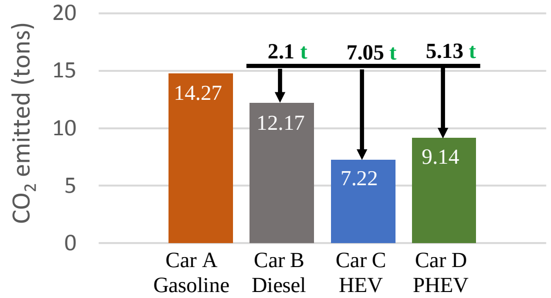

Figure 8: CO_2 emitted per 100,000 km usage

The figure above shows an estimated comparison of CO_2 for a drive of 100,000 kms which is assumed here as the life of a car in India. Though cars in India are driven till around 300,000 kms [3], the battery replacement in HEVs and PHEVs after a period of 50,000 kms is a necessary procedure due to battery degradation [4]. Assuming the gasoline vehicles emissions as the base values, 7.05 tons reduction in CO_2 emission with an HEV and a 5.13 with a PHEV is estimated. However, the CO_2 emitted during manufacturing HEVs and PHEVs is quite high compared to that of Gasoline and Diesel vehicles due to the battery manufacturing.

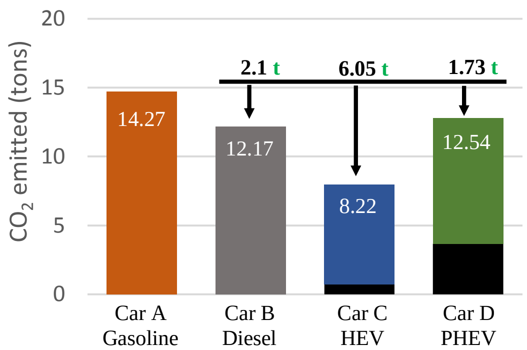

Figure 9: CO_2 emitted per 100,000 km usage along with battery manufacturing emissions

This chart shows an estimation of total CO_2 including the battery manufacturing for the HEV and the PHEV case. Assuming similar battery manufacturing process in India as that of in Japan, the energy required for manufacturing remains the same and hence the CO_2 emitted in case of battery being manufactured in India can be estimated from the CO_2 coefficient in Energy generation in the Indian case. Considering the Japanese battery manufacturing case, the electricity consumption for battery production was obtained from the annual electricity consumption by a battery manufacturer. The manufacturer assembles battery cells and modules from components, such as electrodes and electrolyte. 800kWh for 1kWh of capacity of Li-ion battery production was used for the production process. This evaluates a 1040 kWh (1 ton of CO_2) for the production of HEV battery and 3520 kWh (3.4 tons of CO_2) in case of PHEV.

Hence a value of 6.05 tons of CO_2 reduction in case of HEV and 1.73 tons of CO_2 reduction in case of PHEV have been estimated in comparison to the Gasoline vehicle. Market share of Diesel vehicles in India has been rapidly increasing and presently constitutes the largest percentage among 4-wheeler passenger vehicles, hence comparing the CO_2 reduction in case of PHEV against Car B (Diesel), the emission is higher than that of Diesel by 0.63 tons.

The results assumed the car life to be 100,000 km only, but when the actual value of 300,000 km is taken into account and the PHEV battery replaced every 50,000 km, the CO_2 emission in case of PHEV would result in a large value. For a life of 300,000 kms, the battery needs to be replaced 5 times. This results in an additional 6 time battery manufacturing CO_2 (excluding the end of life processes) to the usage CO_2 emissions.

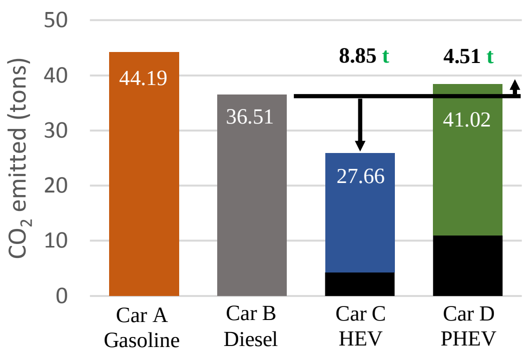

Figure 10: Lifetime (300,000 km) CO_2 emissions

Hence the CO_2 emissions in case of PHEV is 4.51 tons higher to that of the Diesel vehicle while HEV results in an 8.85 tons CO_2 reduction. 4.51 tons increase from the standard diesel vehicle CO_2 emission is a relatively large increase, and hence introducing PHEV into Indian market for reducing CO_2 emissions at this point of time is not an appropriate option. One of the major solutions to this problem could be to refine the energy generation sources to clean energy so as to reduce the CO_2 coefficient in energy generation. As of May 2013, India's power generation from thermal sources is 68% which contributes to the high CO_2 emission coefficient in energy generation. [5]

However a detailed cost analysis including a complete Life Cycle Analysis is necessary for studying the feasibility of such technologies apart from the CO_2 emission reduction.

5.2 Usage Cost Analysis

From the results, a cost estimation in the usage stage of the vehicle was done based on electricity cost, fuel cost etc., First a per day based cost estimation is done considering overnight charging in case of PHEV for the days' use. Fuel cost which values Gasoline at 1.27$/L[6] and Diesel at 0.84$/L[7] as of 16 July 2013 has been used in the study along with household electricity cost which is valued at 0.085$/kWh as on 2013.

Vehicle	Electricity ($)	Fuel ($)	Total ($)
Car A (Gasoline)	0	3.28	3.28
Car B (Diesel)	0	1.81	1.81
Car C (HEV)	0	1.66	1.66
Car D (PHEV)	0.2	0.63	0.83

Table 7: Per day usage cost

Though per day usage cost favors the usage of PHEVs much more than HEV, the initial costs and the battery replacement costs when added to the daily usage values might render PHEV non-feasible for the Indian Market along with the CO_2 emissions. A detailed cost analysis needs a much complicated approach including prediction methods for fuel costs and energy generation strategies along with forex data prediction.

6 Conclusion

Hybrid Electric Vehicles and Plugin Hybrid Electric Vehicles are expected to be a key technology for CO_2 emission reduction in the transportation sector. In this study, CO_2 emissions due to these eco vehicles in Indian case was studied. Firstly, a real time Indian driving cycle was developed to provide a base for this study and also further studies related to this field. Secondly, the CO_2 emission when these vehicles are driven on the Indian roads with Indian driving conditions were estimated by driving the HEV and PHEV on the Chassis Dynamometer on the new driving cycle. In this case, the CO_2 emission in case of HEV was lower than that of Diesel vehicles in India, however a long term estimate on PHEVs showed an adverse result of emitting more CO_2 than the Diesel vehicle. As a conclusion, for a fast pace reduction of CO_2 emission in India, HEVs show a positive results rather than PHEVs. On the other hand, a basic economic study shows that PHEVs are much more cost efficient than HEVs, but the CO_2 reduction is adverse. A solution for this would be to clean up the energy generation sources before India is ready for the PHEV technology, but an easier solution would be to bring changes about its driving behaviour by providing better infrastructure, revising traffic rules etc., so that the higher differentials of speed/acceleration are damped and hence a reduction in CO_2 emissions and increase in fuel economy. The second option would not only reduce the CO_2 emissions in case of PHEVs but also bring about a reduction in the already existing Gasoline and Diesel 4-wheeler passenger vehicles.

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