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Climatic Impacts of Green House Emissions A Case Study on the Public and Private Transportation Sectors of the Asia Pacific

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Abstract—**Societies in Asia have always been plagued with development problems primarily related to imported fossil fuel dependence, fresh water availability, Municipal Solid Waste (MSW) management, transportation and other related problems. The majority of the Islands and rural regions in the Asia-Pacific suffer from large dependence on imported energy. Most developed economies such as Japan and Singapore and developing economies such as India, China and the Philippines deal with hosts of islands in the Asia-Pacific relying on fossil fuel based production and transportation. Among the list of Green House Gases (GHG), Carbon Di-Oxide (CO_2) has always been the top most candidate towards emissions reduction in these countries. CO_2 is well known for its contributions to Global Warming which is reason enough for people to perceive CO_2 as a GHG that needs to be reduced. Until 2007, none of the scientists working on GHG emissions realized that PM emissions and particles such as Soot having high black carbon content were the major reasons for direct absorption of sunlight and a major contributor to Global Warming. The study investigates the need for finding alternate energy potentials in the transport sector which is one of the major contributors of Global Warming and climate change. Quantitative and Qualitative methods of data collection were utilized for the analyses of different types of energy sources and Bio-fuels commonly used by Internal Combustion Engine (ICE) vehicles. A detailed case study of the use of Bio-fuels and battery technologies were compared and evaluated to various renewable energy sources adopted for use in Battery-operated Electric Vehicles (BEV) towards reducing GHG emissions. Detailed emissions calculations and results are also included for discussion.**

Keywords-Green House Gases, Global Warming, Internal Combustion Engine, Battery-operated Electric Vehicles. [1]

I. INTRODUCTION

Public and private transport systems account for the majority of CO_2 and other GHG emissions in the Asia Pacific. Hence, there is an immediate need for reducing GHG emissions in the transportation sector. Although the first electric car was made in the 1830's, automobile engines powered by inexpensive fossil fuels at the time became most popular in the early 1900's. This practically hindered the development and production of electric vehicles (Theresa, 2008). Recent increases in gasoline prices brought renewed interest in electric vehicle research and development in both developed and developing countries bringing phenomenal improvements in both efficiency as well as performance. Today, there is a need to develop new energy storage mechanisms that can replace gasoline towards reducing the world's dependence on fossil fuels. New energy storage and production concepts require rigorous testing to become accepted for use in transportation sectors especially in developing countries which are becoming high energy consumers. This is especially true for Asian countries like India, Japan, Philippines and China having rapid economic growth. Earlier, public transport systems such as trains and buses were the only modes of transport. As the economic well being of these countries started to grow the introduction of private car, luxury transport and private taxi's (cabs) started to become popular. Today, Asian cities are growing so fast that good roads and major changes to city infrastructure takes years to develop. During that time traffic would have grown by a huge percentage that a particular piece of infrastructure would be quickly rendered obsolete. In the long run, some sort of traffic regulation is required. Some disincentives must be put in place as a supplementary solution. A good example of traffic management could come from a neighboring country like Singapore. Sky-rocketing taxes are levied on the purchase of automobiles and the law states that the government will confiscate the car once it has completed ten years service on the road. At the same time, public transportation in Singapore is well planned. The citizens are discouraged to buy cars and encouraged to use a hi-tech public transport system, thus reducing traffic congestion and on road emissions to a certain degree. This model may not work well in most Asian cities due to lack of governing policies particularly in countries like the Philippines due to lack of governance in the transport sector. But similar models and plans could be easily developed, duplicated and implemented in every city.

II. THEMATIC FOCUS

Most Asian cities such as Beijing and Shanghai in China; Chennai, Delhi, Kolkata and Mumbai in India and Island Archipelagos and provinces such as the Marinduque and

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Manila in the Philippines have flat to less than 45 degree landscape inclinations with very little hilly areas. This puts these regions at an advantage for utilizing electric vehicles for public / private transportation which makes it not only economical but also enables regulations in building a pricing model for end consumers in adopting alternate energy technology options (Agarwal, 2008). Taking the example of the Tata NANO, the small car is economical and almost affordable by most middle class to upper class people in India while the same car with more features is sold as the most affordable vehicle in European and western markets in the small car segments. This is not going to help the traffic situation in any way here but instead serves as an example for utilizing alternate energy sources (AFV, 2010). A reduction in private cars through governance and increase in public transportation (including car pooling or sharing) would be ideal for most people to afford. Most of the rail and bus networks are still not very suitable for travel due to non-availability of the desired destinations and safety aspects. Pricing structures constantly change due to dynamic changes in the fossil fuel sector making it impossible to build a standardized economic pricing structure in these countries towards public and private transport. Hence, Electric Vehicles (EV) and the introduction of indigenous bio-fuels such as E80 or B100 would provide for a means to develop high quality public transport systems with next to zero GHG emissions. There will be a substantial decrease in the need for importing fossil fuels as seen in metropolitan cities and rural regions such as Island provinces where energy pricing varies constantly.

III. Methodology

A. Case Study Approach

The research methodology aspects of the study are discussed in this section. This section consists of three parts. The first part details the needs of an automobile service company followed by defining the boundary conditions of the study. The second part describes the main methods of research used in the study namely the case study method which enables the understanding of the conversion process followed by functional aspects of EVs. The final part describes the various Particulate Matter (PM) and soot emission challenges faced by fossil based vehicles and how this in turn becomes a contributing factor to Global Warming. Let us examine the claim that ICEs can be converted into EV's viably. As we can observe, it can be quite a bit of a challenge to write on electric vehicle conversions due to the fact that vast research and literature is available on the subject with untested data sources. Most conversions are handmade due to the fact that government regulations and most governing bodies have their stakes on fossil fuels. After extensive research into the literature available about electric vehicles it can be concluded that it is very difficult to do a comparative analysis of different implementations due to lack of standardization in the technologies utilized for conversions. Hence there is a need to define a set of boundary conditions to enable better readability and clarity on the subject. Two specific areas were considered here towards evaluating our claims: Economic viability (technology transfer) and ecological advantages (Emissions reduction).

B. Research Questions and Specifications

The paper undertakes the study in trying to address the following research questions:

- Can Bio-fuels and alternate energy sources such as solar and wind energy partly or completely replace existing fossil fuels?
- Are Bio-fuels truly carbon neutral fuels?
- Can converting existing ICE vehicles to BEV be economically and ecologically viable?
- Does moving towards alternate energy sources help reduce our carbon footprint and alleviate GHG emissions?

C. Case Study: GHG and PM Emissions

Among the list of GHG, CO_2 has always been the top most candidates towards emission reduction. CO_2 is well known for its contributions to global warming which is reason enough for people to perceive that CO_2 as a GHG needs to be reduced in the first place. Until 2007 none of the scientists working on GHG emissions realized that it was PM such as soot having high black carbon content (<60%) were the major reasons for direct absorption of sunlight and leading to common health problems in people. We need to realize that soot particles are emissions coming from incomplete combustion of high carbon content goods such as wood, biomass and fossil fuels. A number of sources for these emissions would be the constant usage of fossil fuel based vehicles; burning of wood in wood stoves; slash and burn of trees and forests; burning of agriculture wastes and MSW with no proper gasification or cleaning systems. Gas emissions from these sources are not just black smoke with PM that boost global warming but also the major causes for serious respiratory illnesses affecting millions of people. In this research, we talk about the formation of soot and PM's; its emissions potential leading towards faster global warming and the need for filtration technologies and standards such as Euro 5 and 6 towards cleaner emissions. Soot is an unwanted substance that is released by burning fossil fuels such as petrol and diesel fuel, wood and organic matter such as dung. According to the European Environmental Agency (EEA), soot is an impure black carbon with oily compounds obtained from the incomplete combustion of resinous materials, oils, wood or coal (ETDS, 2010). The term incomplete combustion means that the fuel is not fully burnt to its highest temperature. Normally we can get almost 90 % Carbon dioxide and H_2O from complete combustion. Soot consists of carbonaceous particles making it a rich source of carbon. Carbon dioxide and hydrogen ranges from 1:8 to 1:10. Its particles are smaller than the diameter of the human hair which is about 60 micrometer (mm). Soot normally forms at about 140 °C and which can be identified as yellow luminescence when burning candles. Formation of soot consists of several steps. The formation of soot by combustion of natural gas according to the Technical

University of Denmark which consists of fuel pyrolysis (Pyrolysis, 2010) which means a decomposition of the fuel and oxidation reactions, formation of the first ring (benzene) and subsequently Polycyclic Aromatic Hydrocarbons (PAH), formation of the first particles, growth of soot particles due to reactions with gas phase species, particle coalescence, agglomeration and oxidation. As shown in Figure 1a, primary soot particles stick together to form agglomerated masses (Soot Formation, 2002). Soot can stay airborne for a week. It has been sighted on glaciers and icecaps in the Arctic region observed as patches of dark regions. Soot is desired to keep the ongoing process of combustion since the energy radiated by it can cool the flame above the soot growth zone and feed the energy back into the fuel pyrolysis zone. Therefore, it vaporizes it and keeps the reaction going. According to a new study in the journal Nature, soot may be the second biggest contributor to global warming (Jacobson, 2001). Our atmosphere is relatively transparent to the wavelengths of sunlight but not to the thermal radiation that is emitted from the Earth's surface. This radiation passes through the primary gasses in the atmosphere that is Nitrogen, Oxygen and Argon, but Carbon Dioxide, water vapor and other GHG absorb a large proportion of the thermal radiation. This brings about equilibrium between the incident radiation from the sun and the emitted radiation from the earth. The consequence of this is that the temperature tends to become higher than it would have been if the atmosphere had not contained GHG, in fact 330^{o} C warmer. This is called the natural greenhouse effect (Thomas C. Schelling, 1997).

IV. Findings of the Study

A case study of diesel engines trends is chosen to illustrate the trend of soot emissions because diesel engines contribute to a greater percentage of soot in the atmosphere (see Figure 1b). Currently in Japan and other developed countries, there is a trend running against diesel engines and it is done through enforcement of stricter emissions regulations. In Europe by contrast diesel engines are now so popular that it has become an essential market towards preventing overall car sales from slumping. In recent years, the popularity of European cars has been growing in Japan which has led to the extension of the European diesel markets in Japan. Figure 1b shows the Global market share of passenger cars equipped with diesel engines risen above 30% and is now approaching 40%. The monthly statistics also occasionally recorded a diesel share of above 60%. This trend sets out to express the fact that the soot situation in the global atmosphere is only getting worse and given the well outlaid contributions of soot to global warming; it expresses an emergency to act now. So far we have explored the theoretical realms of soot formation and talked of the need for reduction and elimination of PM such as soot having high carbon content. In the next section, we will discuss and evaluate soot and PM emissions for our proposed case study.

Let us take a real world example and see how a Euro 2 specification vehicle (15 Years old) will affect GHG emissions per annum. Soot and PM emissions were calculated for a well know German vehicle the Audi A4 as shown in the Table 1:

Table 1: Emissions from a Typical European Car of EURO 2 Specification

• Audi A4 1.9 TDI Engine: 116 hp • Acceleration time 10.9 s for 0-100 Km /h • Top track speed 196 Km /h • Fuel Consumption 6 liters/100 Km (actual 4.7 – 5.5) • Total Km Run as of 2009: 374, 000 • Car Avg Pricing in 1995: € 21,000	• Distance Driven: Around 50,000 Km in 2 years • Expected Battery Life around 8 years Euro 2 Specs • Estimated CO_2 emitted (@ 175 g/ Km) is 65,450 Kg in 15 Years • Average CO_2 Emissions per year: 4364 Kg pa.

Source: Formulated by Authors

For all oil and oil products, the oxidation factor used is 0.99 (99 percent of the carbon in the fuel is eventually oxidized, while 1 percent remains un-oxidized. Finally, to calculate the CO_2 emissions from a gallon of fuel, the carbon emissions are multiplied by the ratio of the molecular weight of CO_2 (m.w. 44) to the molecular weight of carbon (m.w. 12): 44/12 (IPCC, 2008).

- CO_2 emissions from a gallon of gasoline = 2,421 grams x 0.99 x (44/12) = 8,788 grams = 8.8 Kg/gallon = 19.4 pounds/gallon;
- CO_2 emissions from a gallon of diesel = 2,778 grams x 0.99 x (44/12) = 10,084 grams = 10.1 Kg/gallon = 22.2 pounds/gallon.

As one US gallon is equal to 3.78541178 liters, we can calculate for:

- CO_2 per Liter of Petrol is 8.8 Kg / 3.78541178 Liters = 2.324 Kg;
- CO_2 per Liter of diesel is 10.1 Kg / 3.78541178 Liters = 2.668 Kg.

A calculation was undertaken to see how much CO_2 and PM matter emissions a typical European car would emit. In this case, an AUDI A4 1.9 TDI was taken for the purpose of calculating CO_2 and soot emissions based on Euro 2 specifications. Calculations were also undertaken to understand how the standards such as EURO 1 - 6 enable the need for reduction in PM and Soot emissions. The resulting tables and graphs shown in Figure 2 give us an understanding for the need for filter technologies such as Diesel Particulate Filter (DPF) technologies (DPF, 2010). From Figure 2, it can be observed that the PM emissions also have a significant role in contributing to global warming.

V. LIMITATIONS AND IMPLICATIONS OF THE STUDY

A. Objectives of the Study

This research is based on the case studies aimed at understanding the viability of converting ICE to BEV vehicles followed by emissions evaluation. In a general way, the aim of the research is to enable our findings to create new markets for converting ICE to BEVs and in turn enable sustainable developments through reduction of GHG's. The general objectives of our research are as follows:

- To understand the various public and private transport systems used in the Asia Pacific with specific examples;
- To collect data required for evaluating emissions before and after conversions;
- To understand the need for electric vehicles and to find out markets suitable for deployment by highlighting the economic viability of electric vehicle conversions followed by quantifying the need for emissions reduction in the transportation sector.

B. Revisiting our research questions, implications and Limitations

a) Can Bio-fuels and alternate energy sources such as solar and wind energy partly or completely replace existing fossil fuels?

From our research, there are number of energy sources that could have been identified as a potential for alternate energy source to fossil fuels. The decision to move EV was the ready availability of various battery sources in the regions. From the results of our findings, we can conclude that emissions reduction is considerable when the calculations are scaled up to several vehicles. Although the straight forward argument could be that the sources from which these vehicles are getting charged are from fossil fuels, the impact is justifiable when compared to the emissions reduction results show in Figure 2. Although Bio-fuels such as B100 and E80 could have been utilized it still needs a considerable investment in land and ongoing production costs.

b) Are Bio-fuels truly carbon neutral fuels?

This question can only be answered with the Bio-fuel sources are truly cultivated without hindering the food chain. When comparing and contrasting with bio-fuel sources such as Jatropha or Corn and other organic based Ethanols / Alcohols, etc, the crops are theoretically said to be carbon neutral during the growth phase as the crops absorb CO_2 emissions and flower to produce fruits for the production of Bio-fuels. But from Figure 2, we can observe that the soot emissions are neglected during combustion phase of these fuels in the engines. Although DPF and other technologies increase the temperature to burn more fully the soot and other PM (such as black carbon), vehicles are still producing some form of PM emissions which is negligible in individual vehicles but scales massively when the size of the fleet increases.

c) Can converting existing ICE vehicles to Battery Operated Electric Vehicles (BEV) be economically and ecologically viable?

It is quite economical and ecologically feasible to convert existing ICE engines to BEV's as shown in Figure 2. There is a huge amount of emissions and economical saving in converting an existing ICE vehicle to BEV. The only problem in most developed and developing countries is the increase use of coal and other fossil based energy production which is used for the recharging of the batteries. In some cases, the efficiency and longevity in Lithium Ion (L-ION) batteries have shown improvement in the adoption of EV's, the production and utilization of L-ION technologies has a higher ecological impact in some cases.

d) Does moving towards alternate energy sources help reduce our carbon footprint and alleviate GHG emissions?

Alternate sources of energy enable cleaner production only based on the source itself. A good example of cleaner technological solution would be solar energy. The production of PV panels still need extensive and resource intensive processes to harness the power of the sun as it still serves as a useful and clean alternate energy source. GHG emissions can be dramatically decreased by the adoption of these technologies but the primary markets are already bound to investments tied in the fossil fuel market over the next several decades. Hence, the adoption to alternate energy markets would be slow in the next few decades and we hope to see a better market for such technologies in the future.

VI. CONCLUSION AND FUTURE DIRECTIONS

In this research, we took the opportunity to evaluate PM emissions such as soot and CO_2 emissions towards understanding the need for calculating soot emissions. Most researchers unlike Jacobson do not seem to consider soot emissions (and other PM) in their calculations towards global warming potentials as calculated by us. Unfortunately, research does seem to reflect on these true effects of soot over short periods of time as shown by us; more evidence might be needed for enabling us to understand the true effects of soot towards global warming. It is very clear that any form of emissions need to be cleaned if not avoided towards better safety and health standards for any society. It can be observed that Soot and PM emissions during evaluation of individual vehicles is negligible but scales up quite well when calculated for large fleets. Although our test case fleet size of 25 is quite small, the magnitude of CO_2, Soot and PM emissions are quite observable. Conversion of ICE to BEV has numerous economic and ecological advantages and one of the major advantages is emission control. Although the battery sources are charged with electricity from the Grid coming from a mix of renewable and fossil fuels such as coal (not taken into consideration here), we can still observe that the impact is less than one third than that of direct fossil fuel usage in vehicles.

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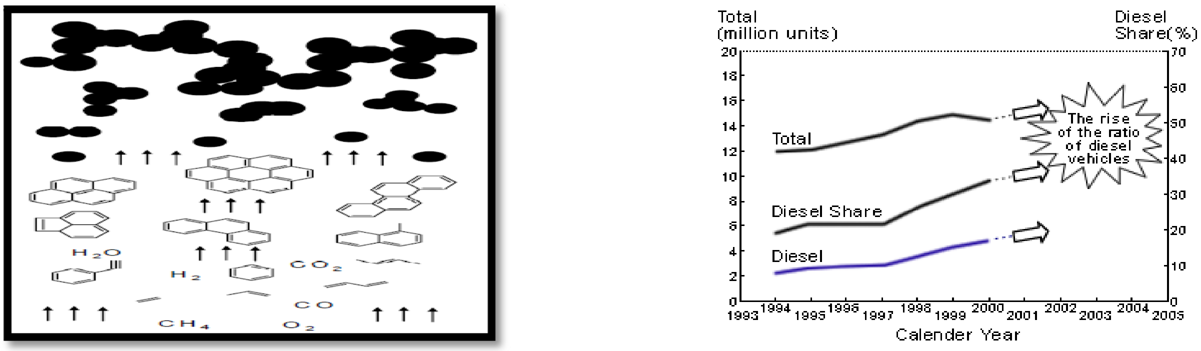

Figure 1. Soot and PM Emissions from the Transport sectors: (a) Soot and Black carbon Schematics (Source:NASA 2010); (b) Diesel Vehicle Market Trends (Source: Diesel, 2010)

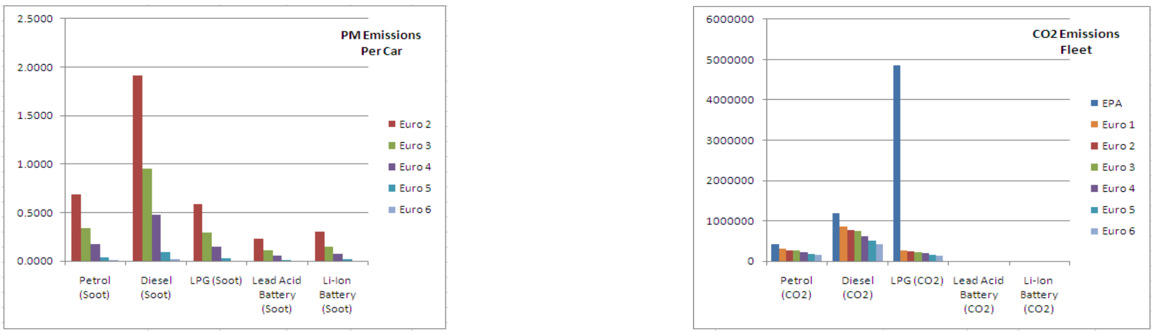

Figure 2. Emissions Study: (a) PM Emissions of our Fleet (Taxis); (b) CO_2e of our Fleet (Taxis).

Source: Formulated by Author based on Euro 2 - 6 Specification (EPA)