UNIVERSITY OF MAURITIUS RESEARCH JOURNAL – Volume 16 – 2010
University of Mauritius, Réduit, Mauritius

Research Week 2009/2010

Carbon Dioxide Emissions Reduction Estimates: Potential Use of Biofuels in Mauritian Transport Sector for Cars and Dual Cars

D Surroop *
Faculty of Engineering,
University of Mauritius
Reduit
Email: *d.surroop@uom.ac.mu*

Z Soheea
Faculty of Engineering,
University of Mauritius
Reduit

Paper Accepted on 11 October 2010

Abstract

One of the major areas of research in clean energy technology for transportation sector is the use of biofuels, and the Government of Mauritius has adopted a strategy of *Building a Green future for Mauritius* through the Maurice Ile Durable (MID) concept through a shift to renewable sources of energy from imported fossil fuels. The present study estimates the respective amounts of carbon dioxide emitted from the transport sector in Mauritius. A predetermined portion of the present engine fuel(s) being used have been replaced by a renewable biofuel (which are gasoline−ethanol fuel blends E10, E15, E20 and E25) to estimate the reductions in the carbon dioxide emissions. The specific objectives of the study were to perform an inventory of the types of vehicles circulating on the roads of Mauritius, estimate the types, and average and maximum quantities of motor fuel consumed, substituting a fraction of the currently used petroleum fuels in cars and dual cars with ethanol to determine CO_2 emissions reduction for 1998−2007, and thereafter making emissions projections for 2008−2017 using a regression technique. Results show that the CO_2 emission kept on increasing each year for Mauritius from the transportation sector. Out of the 1,249,170 tCO_{2e} emitted in 2007, the emissions of $CO_2$from gasoline and diesel were 25 % and 39 %, respectively. 151,950 vehicles using gasoline were circulating on the road in 1998 and in 2007 the amount has increased to 222,344. The emission from cars and dual cars using gasoline was 79,305 tCO_{2e} in 1998 and in 2007 this had increased to 112,746 tCO_{2e}. From the fuel switch the estimated avoided gasoline from E10, E15, E20 and E25 for the year 1998 were 2,900, 4,069, 5,377 and 6,650 tones. These have increased to approximately 4,123, 5,865, 7,607 and 9,349 tones the different gasoline−ethanol blending in 2007. The avoided CO_2 emission from E10 was 9,216 tones CO_2 in 1998 and increased to 13,102 tons in 2007.Thus, the percentage reduction of CO_2emission using E10 was found to be 3.2% in 1998 and this increased to 4.1% reduction of CO_2 in 2007. Using E25, a drastic reduction of the emission in 1998 where approximately 21,131 tCO_{2e} was avoided using E25 and in 2007 the amount avoided was 29,709 tCO_{2e}. This represents a reduction in CO_2 emissions of 7.5% in 1998 compared to 9.4% in 2007 using E25. Projections were made for 2008−2017 and it was found that using E10 as a biofuel fuel in the transportation sector will save about 80,755 tones of gasoline and the resulting total avoided CO_2 emission for the year 2008−2017 will reduce to approximately 188,604 tCO_{2e}. E25 showed a more positive effect as the total avoided gasoline for the projected year 2008−2017 was found to be 184,943 tones and avoided CO_2 was 411,946 tCO_{2e}.

Keywords: Carbon dioxide; Transport; Biofuel; Gasoline−ethanol blends; Emissions reductions.

**For correspondences and reprints*

1. INTRODUCTION

The transport sector is amongst the fastest growing economic sectors in both developed and developing countries and globally contributes to about 24% of global carbon dioxide (CO_2) emissions (Auffhammer and Carson, 2008). Global transport−related greenhouse gas (GHG) emissions are currently rising by 2.5% annually. The increase of CO_2 emissions will have an adverse effect on the climate and the consequences are very disastrous. Thus, promoting the use of biofuels to mitigate GHG emissions will have a positive effect in the long run.

One of the major areas of research is promising use of biofuels. Biofuel is a generic term for fuels that can be produced from or are made up of a renewable material of plant or animal origin. It can be used to displace fossil transportation fuels and their associated emission of CO_2. Biofuels appear to offer no net CO_2 emissions and reduce dependence on fossil fuels. Biofuels used in transport are typically bioethanol which is used as a gasoline substitute and bio−diesel which is used as a diesel substitute.

Mauritius has equally experienced a significant increase in the number of motor vehicles. This continual increase in flux of transport is leading to consequential impacts on the environment in Mauritius, especially in terms of vehicular emissions which have occasioned higher GHG emissions in the atmosphere of the country, the formation of photochemical smog, acidification, eutrophication, human and ecological health depredation (Von Blottnitz and Curran, 2007) and a general disruption in several strata of the biospheres on Earth. This growth in the number of vehicles has also been accompanied by a corresponding rise in energy consumption and carbon dioxide emissions in the transport sector. The rising demand in energy and the soaring prices of oil has practically urged the Government of Mauritius to resort and adopt the strategy of *Building a Green future for Mauritius* through the Maurice Ile Durable (MID) concept through a shift to local renewable sources of energy away from imported fossil fuel.

The present study was performed for two time periods (1998−2007 and 2008−2017), in a first instance, to estimate the amounts of carbon dioxide emitted from the transport sector in Mauritius through the use of diesel and gasoline for motor vehicles. In the second part of the study, a predetermined portion of the present engine fuel(s) being used was replaced by a renewable fuel (E10, E15, E20 and E25) which is a gasoline−ethanol blend, to estimate the reduction in the carbon dioxide emissions.

2. ETHANOL−GASOLINE BLENDS (GASOHOL'S)

Ethanol as a motor fuel is found in various forms around the world, in blends together with gasoline and diesel containing different amounts of water. Fuel producers design fuel blend specifications to suit local legislation, vehicles, weather, consumer habits and other conditions on the market in which they operate. Somewhat more than half of the fuel ethanol used worldwide is used as an additive to gasoline, meaning that ethanol constitutes 5−10% of the overall fuel mass in the blend. There are two major reasons for using ethanol as an additive to gasoline, apart from any reduction in CO_2 emissions. Firstly, the high octane rating of ethanol will by adding ethanol to gasoline raise the octane number of the fuel blend, thus guarding against engine knock which can damage the engine. Secondly, the fact that ethanol contains oxygen will make ethanol containing gasoline burn cleaner and reduce the amount of harmful emissions of carbon monoxide (CO), particulates and unburned gasoline components. One such patented blend is the E−diesel blend, consisting of 15% anhydrous ethanol sometimes including additives and about 85% diesel fuel. Another trademark blend, O_2−diesel, consists of 7.7% anhydrous ethanol in diesel fuel, and is in use with success in more than 5000 buses in Karnataka (Rae, 2007).

To reduce the net contribution of GHGs to the atmosphere, bioethanol has been recognized as a potential alternative to petroleum−derived transportation fuels (Govindaswamy and Vane, 2007). Fuel ethanol blends are successfully used in all types of vehicles and engines that require gasoline. A study conducted by Rahman et al. (2007) has shown that bioethanol is an oxygenated fuel that contains 35% oxygen, which reduces particulate and NO_x emissions from combustion. According to de Oliveria et al. (2005), the most popular blend for light−duty vehicles is known as E85, and contains 85% bioethanol and 15% gasoline. In Brazil, bioethanol for fuel is derived from sugar cane and is used pure or blended with gasoline in a mixture called gasohol (24% bioethanol, 76% gasoline). In several states of the United States, a small amount of bioethanol (10% by volume) is added to gasoline, known as E10. Blends having higher concentrations of bioethanol in gasoline are also used, e.g. in flexible−fuel vehicles that can operate on blends of up to 85% bioethanol—E85 (Malca and Freire, 2006)

3. GHGS EMISSION PERFORMANCE OF ETHANOL BASED BIOFUELS

Since the production process of ethanol is simpler and more efficient, pure ethanol is produced and since there are no external reactants in the ethanol, the ethanol combustion reaction, is a pure reaction with no other products being produced besides carbon dioxide and water. In contrast to the many extraneous products of the petroleum combustion reaction, the carbon dioxide and water vapor are significantly less harmful to the environment than the synthetic gases produced by petroleum fuels.

Numerous authors have confirmed that the oxygen combined in with ethanol influences beneficially the gasoline combustion process, decreasing the content of carbon monoxide and unburned hydrocarbons in the exhaust gases (Yüksel and Yüksel, 2004). Research made by Kowalewicz (2005) showed that, at the optimum ethanol concentration in gasoline, the emissions of hydrocarbons and CO can be reduced by 10% and 20–30%, respectively. In the study of Yacoub et al. (1998), alcohols with carbon numbers ranging from C_1 to C_5 were individually blended with unleaded test gasoline. The performance characteristics of the blends were quantified using a single−cylinder spark ignition engine. It was observed that adding lower alcohols (C_1, C_2 [ethanol] and C_3) to gasoline improved the knock resistance. Generally, all alcohol−gasoline blends showed reduction in CO emissions. Zhai et al. (2009) recently evaluated the differences in fuel consumption and tailpipe emissions of flexible fuel vehicles operated on E85 versus gasoline. It has been found that the differences of average E85 versus gasoline emission rates for all vehicle models are −22% for CO, 12% for HC, and −8% for NOx emissions, which imply that replacing gasoline with E85 reduces CO emissions, may moderately decrease NOx tailpipe emissions, and may increase HC tailpipe emissions. On a fuel life cycle basis for corn−based ethanol versus gasoline, CO emissions are estimated to decrease by 18%. Life−cycle total and fossil CO_2 emissions are estimated to decrease by 25 and 50%, respectively.

4. METHODOLOGY

To be able to calculate the total CO_2 emitted each year for a fossil fuel, the CO_2 emitted by each fossil fuel must be calculated. The method to calculate the individual emissions was taken from the "*UNFCCC/CCNUCC Approved baseline and monitoring methodology AM0031 "Baseline Methodology for Bus Rapid Transit Projects*[1]".

4.1 Estimation of CO_2 emissions by fossil fuel

The estimation of CO_2 emissions from the combustion of individual fuel types has been evaluated using the following equation ('Equation 9' in AM0031).

$$PE_y = \sum_x \left[TC_{PJ,x,y} \left(EF_{CO_2,x} + EF_{CH_4,x} + EF_{N_2O,x} \right) \right]$$

Where $\mathbf{PE_y}$ = Project emissions in year y (tCO_{2e}), $\mathbf{TC_{PJ,x,y}}$ = Total consumption of fuel type x in year y by the project (million liters), $\mathbf{EF_{CO2,x}}$ = CO_2 emission factor for fuel type x (gCO_2 per liter), $\mathbf{EF_{CH4,x}}$ = CH_4 emission factor for fuel type x (gCO_{2e} per liter, based on GWP) and $\mathbf{EF_{N2O,x}}$ = N_2O emission factor for fuel type x (gCO_{2e} per liter, based on GWP). The NCV and emission factors are given in Tables 1 and 2.

[1] AM0031isavailableathttp://cdm.unfccc.int/UserManagement/FileStorage/TKF9YBPE4R2A3L1V87CSXQWOZDI0HN

The total annual CO_2 emissions was then determined as

$$PE_{yTotal}, tCO_{2e}/yr = PE_{y,gasoline} + PE_{yDiesel} + PE_{yAviation\ fuel} + PE_{yLPG}$$

TABLE 1 NCV values and density for fossil fuels

Fuel	NCV (kJ/kg)	Density (kg/L)
Gasoline[a]	44,193.38	0.735
Diesel[b]	42,900.00	0.827
Aviation Fuel[c]	44,155.91	0.715
LPG[d]	46,392.33	0.499

[a]:WORLD BANK. 1981 *Energy pricing in developing countries*, by A. de Julius. Washington, D.C., World Bank Energy Department.

[b] Leach, G. 1985 A handbook on domestic energy consumption in developing countries. London, International Institute for Environment and Development. (Draft)

[c] Source: http://ces.iisc.ernet.in/energy/paper/alternative/calorific.html

[d] Source: http://www.fao.org/docrep/r6560E/r6560e03.htm

TABLE 2 Emission factors (gCO_{2e}/L)

Fuel	CO_2	CH_4	N_2O
Gasoline	2313	12	10.5
Diesel	2661	1.5	26.67
Aviation Fuel	2183.64	–	–
LPG	1464.45	–	–

Source: Intergovernmental Panel on Climate Change (IPCC), 2006 IPCC Guidelines for National Greenhouse Gas (Approved baseline and monitoring methodology AM0031 "Baseline Methodology for Bus Rapid Transit Projects")

4.2 Avoided gasoline from fuel switch

To calculate the volume of the avoided gasoline following a fuel switch with E_X, an energy balance was firstly performed to calculate the volume of the different E_{Blend} to be used per blend during the fuel switch. Then the amount of gasoline which was used in the E_{Blend} was determined. The difference between the total unblended volume of gasoline and the gasoline used in a particular blend for a particular year is the avoided volume gasoline estimate. The following equation was used to determine the above set of data.

Energy Balance

$$Y \times Volume\ of\ E_{Blend} \times NCV\ of\ E_{Blend} = Volume\ of\ Gasoline \times NCV\ of\ Gasoline$$

Thus,

$$Volume\ of\ E_{Blend},\ kilolitre/year = \frac{Volume\ of\ Gasoline \times LHV\ of\ Gasoline}{Y \times LHV\ of\ E_{Blend}}$$

Where

$\boldsymbol{Y} = \frac{100}{Coefficient\ of\ E_{Blend}}$ and NCV of E_{Blend} (kJ/L) = (V × $NCV_{Ethanol}$) + (1−V) × $NCV_{Gasoline}$)

with NCV of gasoline (kJ/L) = $NCV_{gasoline}$.

The volume of the unblended gasoline (kilolitre/year) was determined as

$$Volume\ of\ Gasoline\ in\ Car + Volume\ of\ Gasoline\ in\ Dual\ Car$$

$$= \frac{(0.7 \times 0.95 \times Car) + (0.3 \times Dual\ Car)}{T_{Gasoline}} \times \quad TC_{PJ,y,Gasoline}$$

The volume of gasoline used in E_{Blend} was determined from the following formula

$$Volume\ of\ gasoline\ in\ E_{Blend},\ kilolitre/Year = Z \times Volume\ of\ E_{Blend}$$

where $Z = \frac{100}{Coefficient\ of\ E_{Blend}} - 1.$

It has been assumed that out of 5% car which was driven by LPG, 70% of it was driven by gasoline and 30% dual car was driven by gasoline. Thus, the volume of the avoided gasoline is calculated as follows using the above individual term simplifications:

Volume of avoided Gasoline, kilolitre/Year = Volume of E_{Blend} *– Volume of gasoline in* E_{Blend}

4.3 Avoided CO_2 emissions from fuel switch

To estimate the avoided CO_2 emissions, the emission factor from gasoline, $EF_{gasoline}$ was first obtained from the following equation (taken from Equation 9 in AM0031.):

$$EF_{gasoline}\,(tCO_{2e}/kL) = EF_{CO_2,x} + EF_{CH_4,x} + EF_{N_2O,x}EF$$

Thus, the avoided CO_2 emissions for a specific bioethanol blend for a specific year was calculated as follows:

$$Avoided\ CO_2\,(tCO_{2e}/year) = EF_{gasoline} \times Volume\ of\ avoided\ Gasoline\ in\ blend\ E_X$$

5. RESULTS AND DISCUSSIONS

The inventory estimates for the CO_2 emissions from transport sector for Mauritius are shown in Figures 1 and 2. The CO_2 emissions have been estimated for gasoline and diesel driven vehicles from the period 1998−2007. The estimates for the aviation fuel also were estimated. . Out of the 1,249,170 tCO_{2e} emitted in 2007, the emissions of CO_2 from gasoline and diesel were 25 % and 39 %, respectively. The CO_2 from diesel have been estimated at 386,739 tones in 1998, increasing up to 564,786 tones in 2006 and decreasing again to 493,541 in 2007. On the other hand, gasoline fuel showed an increase of 281,505 tones in 1998 to 314,386 tones in 2007. It is noted that the emissions of CO_2 are higher from diesel driven vehicles as compared to gasoline driven vehicles in the city.

The contribution of pollutants emission from diesel vehicles showed rising trends during the period of inventory, indicating a plausible increasing preference for diesel driven vehicles in Mauritius due to its lower price as compared to gasoline per liter. For instance, the price of diesel per liter is Rs 32.65 compared to gasoline which is at Rs 40.40, thus a difference of Rs 7.75 per liter. The emissions from gasoline vehicles increasingly seemed to contribute in the transport sector emissions during the period of inventory. This could be accounted most realistically by an increase and preference in personalized mode of transport over public transport due to an increase in the standard of living of people.

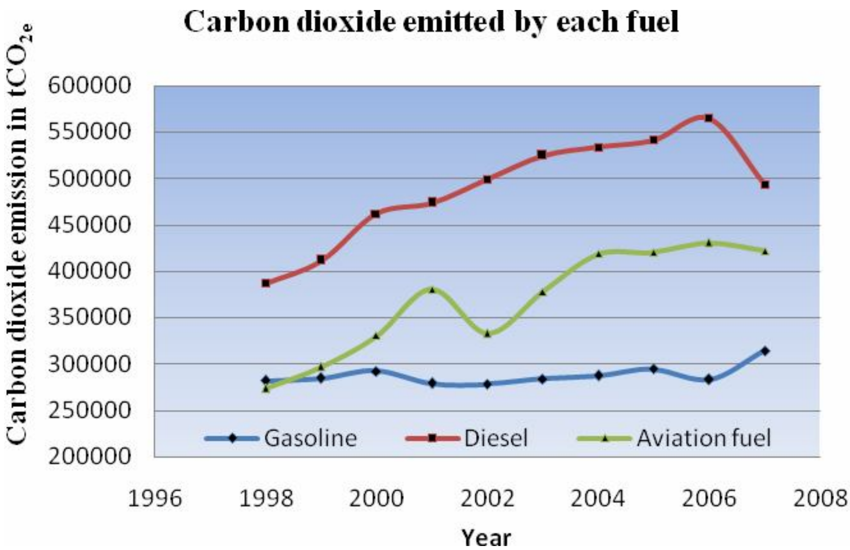

Figure 1: Carbon dioxide emission from Gasoline, Diesel and Aviation fuel

In the aviation sector, the CO_2 emission increased from 273,449 tones in 1998 to 380,692 tones in 2001. A decrease to 332,805 tones was experienced in 2002. The amount of CO_2 then showed an increase of 377,562 in 2003 to 421,775 tones in 2007. This increased and decreased amount of the CO_2 emissions depends greatly on the arrival of tourists in Mauritius. It is estimated that the number of tourists arrivals for the year 2007 rose to 11% to reach 875,000, compared to 788,276 in 2006. Thus, more fuel was used in the aviation sector resulting in an increase in the CO_2 emission.

Figure 2 shows a drastic increase in the CO_2 emissions from LPG. In 1998, the emissions were 774 tones which gradually increased up to 20,211 tones in 2005 and dropped to 19,466 tones in 2007. The drastic increase of CO_2 from LPG is due to the highly used amount of LPG in car since it is more energy intensive as it occupies less space when compressed. However, the emissions are far less than that of gasoline and diesel.

Figure 3 shows the carbon dioxide emitted from cars and dual cars. It was assumed that 70% are cars and 30% dual cars, and driven by gasoline. 151,950 vehicles using gasoline were circulating on the roads in Mauritius in 1998 and in 2007 the amount had increased to 222,344. The emission from cars and dual cars using gasoline was 79,305 tCO_{2e} in 1998 and in 2007 this had increased to 112,746 tCO_{2e}. Moreover, diesel fuel also experienced an increased in the emissions of CO_2 from 1998−2006. The amount increased from 201,722 tonnes to 311,765 tones and there was a decrease in the emissions in 2007 which amount to 276,582 tones. This might be because of the oil crisis which Mauritius was experiencing.

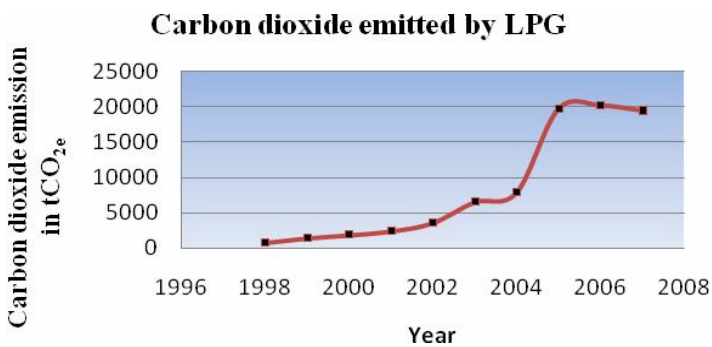

Figure 2: Carbon dioxide emitted by LPG

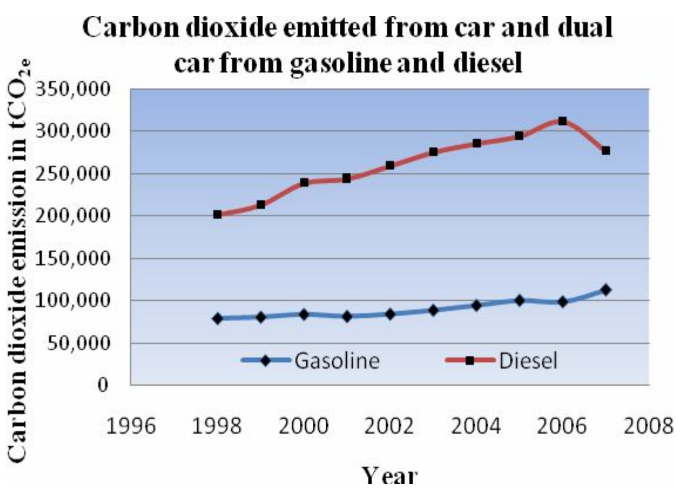

Figure 3: Carbon dioxide emitted from car and dual car

In the second part of the study, a predetermined portion of the present engine fuel(s) being used have been replaced by a renewable biofuel (which are gasoline–ethanol fuel blends E10, E15, E20 and E25) to estimate the reduction in the carbon dioxide emissions. These reductions are shown in Figures 4 and 5.

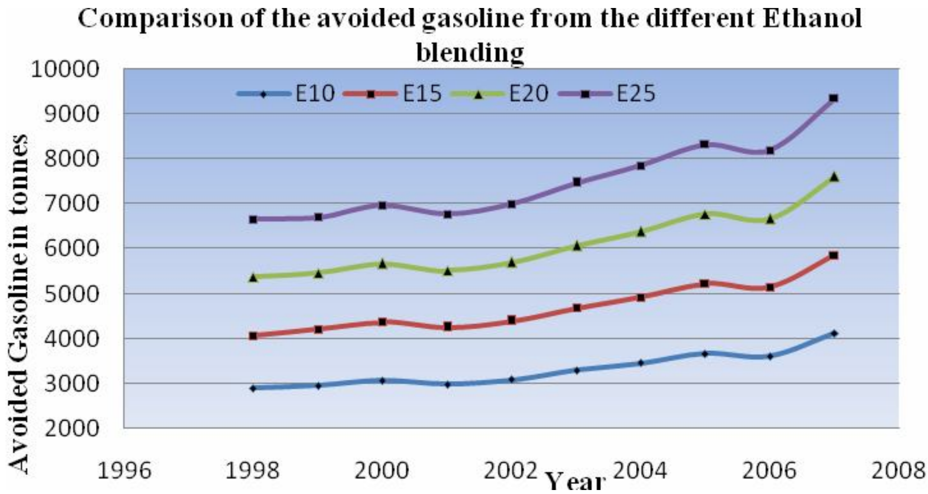

Figure 4: Comparison of the avoided gasoline from the different ethanol blending

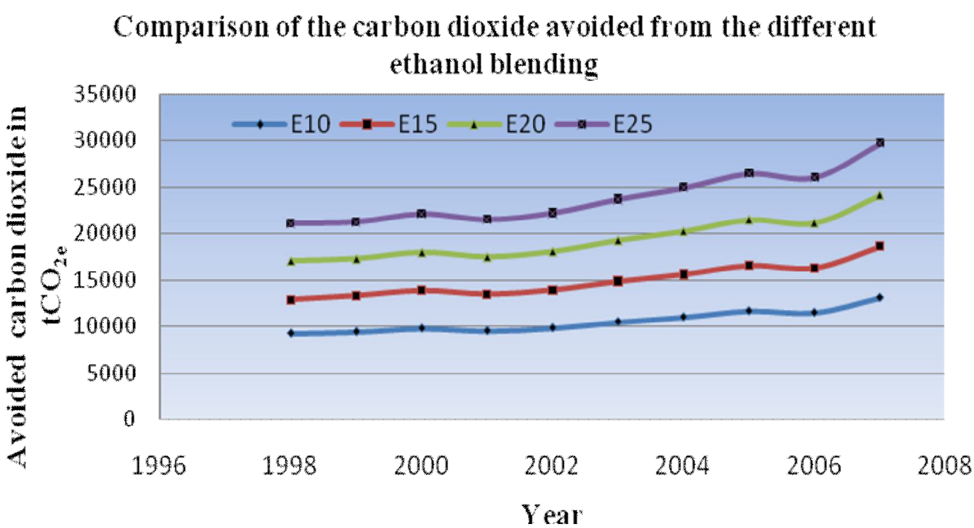

Figure 5: Comparison of the carbon dioxide avoided from the different ethanol blending

The avoided gasoline quantities from the different fuel switch were calculated. From the fuel switch, the estimated avoided gasoline from E10, E15, E20 and E25 for the year 1998 were 2,900, 4,069, 5,377 and 6,650 tones, respectively. These have increased to approximately 4,123, 5,865, 7,607 and 9,349 tones, respectively, for the different gasoline−ethanol blending in 2007. The avoided CO_2 emission from E10 was 9,216 tCO_{2e} in 1998 and increased to 13,102 tCO_{2e} in 2007.Thus, the percentage reduction of CO_2emission using E10 was found to be 3.2% in 1998 and this increased to 4.1% of CO_2 in 2007. Using E25, a drastic reduction of the emission in 1998 where approximately 21,131 tCO_{2e} was avoided using E25 and in 2007 the amount avoided was 29,709 tCO_{2e}. This represented a reduction in CO_2 emissions of 7.5% in 1998 compared to 9.4% in 2007 using E25.

Finally, projections were made for 2008−2017 and it was found that using E10 as a biofuel fuel in the transportation sector will save about 80,755 tones of gasoline and the resulting total avoided CO_2 emission for the year 2008−2017 will reduce to approximately 188,604 tCO_{2e}. E25 showed a more positive effect as the total avoided gasoline for the projected year 2008−2017 was found to be 184,943 tones and avoided CO_2 was 411,946 tCO_{2e}. Figures 6 and 7 represent the avoided gasoline and carbon dioxide emissions for the ethanogasoline blends.

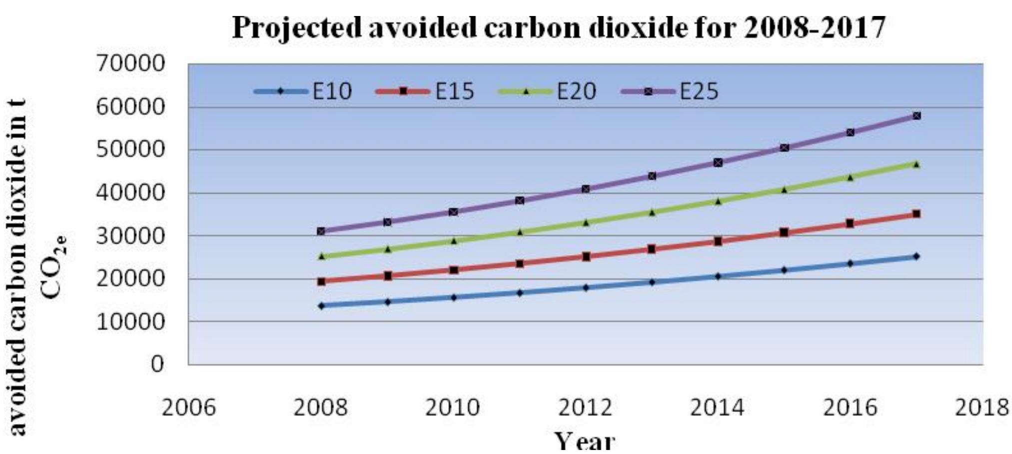

Figure 6: Projection of the avoided gasoline

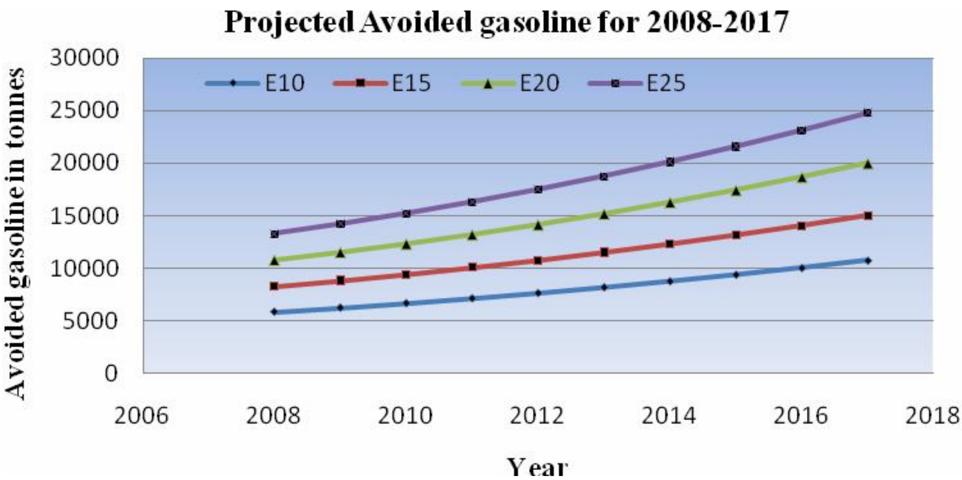

Figure 7: Projections of the avoided Carbon dioxide

6. CONCLUSIONS

There are several reasons why biofuels are considered relevant technologies by both developing and industrialized countries. They include energy security, environmental concerns, foreign exchange savings, and socio–economic issues related to the rural sector. Due to its environmental merits, the share of biofuel in the automotive fuel market will grow fast in the next decade (Demirbas and Balat, 2006). The advantages of biofuels are that they are easily available from common biomass sources and they are environmentally friendly due to its no release in carbon dioxide. E25 is a more promising biofuel in the transportation sector and it may be expected that a fuel switch to biofuel E25 for the transportation sector will bring considerable carbon dioxide emissions reductions which could earn carbon credits to Mauritius under a Clean Development Mechanism (CDM) project activity.

7. REFERENCES

AUFFHAMMER, M., CARSON, R.T. (2008) Forecasting the path of China's CO2 emissions using province–level information.Journal of Environmental Economics and Management, 55(3), 29–247.

DEMIRBAS, M.F., BALAT, M. (2006). Recent advances on the production and utilization trends of bio-fuels: A global perspective. Energy Conversion and Management, 47(15-16), 2371−2381.

DE OLIVERIA, M.E.D., VAUGHAN, B.E., RYKIEL, JR. E.J. (2005). Ethanol as fuel: energy,carbon dioxide balances, and ecological footprint. BioScience, 55, 593–602.

GOVINDASWAMY, S., VANE, L.M. (2007). Kinetics of growth and ethanol production on different carbon substrates using genetically engineered xylose−fermenting yeast. Bioresource Technology, 98, 677–685.

KOWALEWICZ, A. (2005). Combustion characteristics of compression ignition engine fueled with RME and ethanol. Journal of KONES International Combustion Engines, 12 (1–2), 163–173.

MALCA, J., FREIRE, F. (2006) Renewability and life−cycle energy efficiency of bioethanol and bio−ethyl tertiary butyl ether (bioETBE): assessing the implications of allocation, 31, 3362–3380.

RAHMAN, S.H.A., CHOUDHURY, J.P., AHMAD, A.L., KAMARUDDIN, A.H. (2007). Optimization studies on acid hydrolysis of oil palm empty fruit bunch fiber for production of xylose. Bioresource Technology, 98, 554–559.

RAE, A. 'Kanataka Bus Fleet Switching to Ethanol−Diesel Blend', website of Green Car Congress, Jan. 2007.

VON BLOTTNITZ, H., CURRAN, M.A. (2007) A review of assessments conducted on bio−ethanol as atransportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective. Journal of Cleaner Production , 15(7), 607−619.

YACOUB, Y., BATA, R., GAUTAM, M. (1998). The performance and emission characteristics of C_1−C_5 alcohol−gasoline blends with matched oxygen content in a single−cylinder spark ignition engine. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy. 212(5), 363−379.

YÜKSEL, F., YÜKSEL, B. (2004). The use of ethanol−gasoline blend as a fuel in an SI engine. Renewable Energy, 29, 1181–1191.

ZHAI, H., FREY, H.C., ROUPHAIL, N.M., GONÇALVES, G.A., FARIAS, T.L. (2009). Comparison of flexible fuel vehicle and life−cycle fuel consumption and emissions of selected pollutants and greenhouse gases for ethanol 85 versus gasoline. Journal of Air Waste Management Association, 59(8):912−24.