International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 3 Issue 7 ǁ July. 2015 ǁ PP.48-55

Comparative Computational Modelling of CO_2 Gas Emissions for Three Wheel Vehicles

Chidiebere Metu, Sunday Christopher Aduloju*, David Agarana, Elizabeth Udeh, Sumaila Onimisi Sheidu
National Engineering Design Development Institute,PMB 5082, Nnewi Anambra State, Nigeria.

ABSTRACT
Quest for a greener environment and energy conservation has led a number of research studies to increase fuel economy and reduce emissions in developmental design of vehicles.This study illustrates how a vehicular body shape affects fuel consumption and gas emission. Solid models for two different tricycles were done and simulated using Solid works flow xpress, Mathematical models were applied to compare the rate of fuel consumption and gas emission between the simulated models. The result shows thatNASENI TC1 consumes less fuel and invariably emits less CO_2 when compared with RFM 1.

I. INTRODUCTION

Fuel economy is described as that proportion of energy released by a fuel combustion process which is converted into useful work[1].For vehicles, it is measured in miles per gallon (MPG) in USA or kilometers per litre (km/L) in places like Netherlands, Denmark, etc. it is also known as fuel consumption in some part of the world like Europe, Canada, New Zealand and Australia and it is measured in (L/100km) [2].

In 2004, on the average cars in the United States of America have 8.7L/100km as its fuel consumption rate and in 2012 cars in the European countries have 5L/100km on the average, likewise for motorcycles the fuel consumption ranges from 1.5L/100km to about 2.8L/100km [3].This shows a remarkable decrease when compared to that of cars because of the specifications of the engine. The fuel consumption from different samples of tricycles ranges from 2.8L/100km to 4L/100km [4]. This range in fuel consumption also depends on the specification/type of the engine and also varies between manufacturers. Larger engine type consumes more fuel [5]. Generally, modern vehicles are designed to have a better fuel economy without compromising any of its design criteria.

Numerous factors are known to affect the fuel consumption of vehicles and developing ways to reduce these factors could be achieved during vehicle design.Some of these factors are internal while the rest are external. The internal factors depend on the engine capacity and mechanical components of the vehicle while the greatest external factor is air resistance or drag force [6]. Drag force is the external force that opposes the direction of thrust of a vehicle and it is expressed as: [6]

$$D = \frac{1}{2} C_d \rho A V^2 \qquad \text{--} 1$$

Where:
D is the drag force in Newton
C_d is the coefficient of drag
$\rho$is the density of air in kg/m^3
A is the frontal area in m^2
V is the velocity of the vehicle in m/s.

Reduction of it reduces the amount of fuel consumed and also reduces the amount of air pollution/greenhouse gases (GHG) emitted to the atmosphere.Air pollution is defined as the adulteration of air by discharge of dangerous substances, which can cause health difficulties including burning eyes and nose, itchy irritated throat and breathing problems [7].GHG emissions pose a threat to living organisms and also influence climate change / global warming. This emission causes a rise in the temperature of the earth as a result of ozone layer depletion from the actions of GHG which allows the entrance of sun rays and other dangerous elements into the atmosphere therefore increasing the temperature of earth. These have great dangers to humans and other living organism.High concentration of GHG emission can lead to various illnesses like cancer, birth defects, brain damage, nerve damage, long term injury to the lungs, injury to breathing passages and even death when exposed over a period of time [8]. At present, climate change is speedily becoming famous as tangible problem that must be addressed to evade major ecological consequences in the future, if we are to have a more ecofriendly environment.Scientific American noted that 2014 is the hottest year on record for the planet with global temperatures 1.03 degrees Fahrenheit higher than the 1961-1990 average record [9]. All these problems are caused by air pollution from transportation sector, volcanic ash and gases, smoke and trace gases from forest fires etc. [8]

The transportation sector is known to be one of the contributors of GHG emissions in developing and developed countries. Although some developing countries do not have a good record of emission's caused by transportation sector, developed countries like America does. Cline (1991) specified that transportation accounts for an essentialelement of greenhouse gases (especially CO2) emission [10].It is a major contributor of carbon dioxide (CO_2) and other GHG emissions from human activity, accounting to approximately 14% of total anthropogenic emissions globally [11]. These anthropogenic emissionsinclude carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and fine particles, these compounds are known to play a major role in air pollution. United States Environmental Protection Agency (USEPA) reported that transportation sources were responsible for 77% of CO emissions, 45% of NOx, 36% of volatile organic compounds, and 22% of particulates in the US during the year 1993 [12]. USEPA (2012) also reported that the transportation sector accounts to about 28% of the total GHG emission in United States of America, which is equivalent to 1827.28 million metric tons of CO_2 emission [13].Cars, trucks, motorcycles, and buses are known to emit significant quantities of these anthropogenic compounds [14].

Minimizing the use of fuel in order to reduce emissions in the transportation sector is an important short-term and long-term goal. In order to reduce the amount of fuel consumption, more fuel efficient vehicle models should be produced as well as operating exiting ones efficiently. The most simple and conveniently implemented method used in the estimation of fuel consumption is based on utilization of mathematical models. Evaluating fuel efficiency is an important factor to consider while designing vehicle. Based on this, evaluation is usually performed via mathematical modeling and simulation, the main constructive parameters of the vehicle may bedetermined at the design stage and steps to reduce fuelconsumption may be taken [15]. Several mathematical models for estimating fuel efficiency and gas emissions are described in literature. Generally, analytical mathematical models used in computation of fuel consumption and gas emission in vehicles due to drag effect can be applied to tricycles.

Comprehensive studies on dynamic stability and aerodynamics analysis on Cargo-type tricycles has been done by authors of [16, 17]. This paper focuses on the comparative analysis of fuel consumption and gas emissions of two models of cargo-type tricycles with reference to their body shapes. The first model is the referenced model (RFM1) while the second model (NASENI TC1) is the tricycle designed and constructed by National Engineering Design and Development Institute (NEDDI) Nnewi, an institute under National Agency for Science and Engineering Infrastructure (NASENI). The tricycles are modeled and simulated using Computational Fluid Dynamics (CFD) capability of Solidworks flowxpress software and the necessary data needed for analysis were generated. The use of the software and mathematical models reduces the need for costly physical testing and prototyping.

Metu et al, (2014) did an extensive review of the mathematical models available in estimating the fuel consumption of tricycles. In their work, they opined the use of mathematical model formulated by Silvia et al. The proposed model evaluates fuel consumption Q_s measured in litres per 100km, on the basis of hourly fuel consumption and engine via the following relation [18]

$$Q_s = \frac{g_e(P_{rl}+P_w+P_a)}{10V_a\eta_T\rho_f} \quad \text{--2}$$

Where

g_e is the specific fuel consumption, g·kWh-1

P_{rl} is the power required to overcome the rolling resistance of the road, KW

P_w is the power required to overcome the resistance of air, kW

P_a is the power required to overcome the resistance of inertial acceleration, kW,

V_a is the average speed of the vehicle, km/h

η_T is the efficiency of transmission

ρ_f is the fuel density in kg/l

Equation 2 assumes that the vehicle constantly operates in acceleration mode, Specific fuel consumption is assumed to be constant and at optimal and the engine power is determined according to this assumption.

For vehicles/tricycles travelling at the speed of 113km/hr (70miles/hr) and above, 65% of the power generated is used to overcome drag force at this speed[19]. Thus the total power can be simplified by taking aerodynamic drag force into consideration as shown;

$$\text{Power} = \frac{D\times V}{0.65} = \frac{C_d A\rho V^3}{1.3} \quad \text{--3}$$

Where

D is the drag force

V is the velocity of the vehicle/tricycle

Cd is the coefficient of drag
ρ is the density of air in kg/m^3
A is the frontal area in m^2

The easiest and most accurate way of calculating transport emissions is to record energy and/or fuel use and employ standard emission conversion factors to convert energy or fuel values into CO_2 emissions [20]. Every liter of fuel consumed will result into a certain amount of CO_2 emissions. The energy based method uses the following formula in calculating emissions

CO_2 emissions = FC x FECF --4
Where,
FC is the fuel consumption in litres and
FECF is the fuel emission conversion factor
Table 1 below gives the fuel emission conversion factor for different kind of fuels used in Kg CO_2/litre or in Kg CO_2/kg

Table 1: Wheel to well Fuel Emission Conversion Factor

Fuel type	**Kg CO_2/litre**	**Kg CO_2/kg**
Motor Gasoline	2.8	
Diesel Oil	2.9	
Gas Oil	2.9	
Liquefied Petroleum Gas (LPG)	1.9	
Compressed Natural Gas (CNG)		3.3
Jet kerosene		3.5
Residual Fuel Oil		3.5
Biogasoline	1.8	
Biodiesel	1.9	

Source: Guidelines for Measuring and Managing CO_2 Emission from Freight Transport Operations Cefic, and ECTA (2011)

II. Methodology

Computational Fluid Dynamics (CFD) simulations were carried out for Referenced Model (RFM 1) and National Agency for Science and Engineering Infrastructure Tricycle Cargo (NASENI TC1). The drag forces were generated for the two models at different speed of 40Km/h, 50Km/h, 60Km/h, 70Km/h, 80Km/h, 90Km/h and 100Km/h. Parameters considered in the simulation are drag force, air density, coefficient of drag and frontal area, all are shown in tables 2 and 3

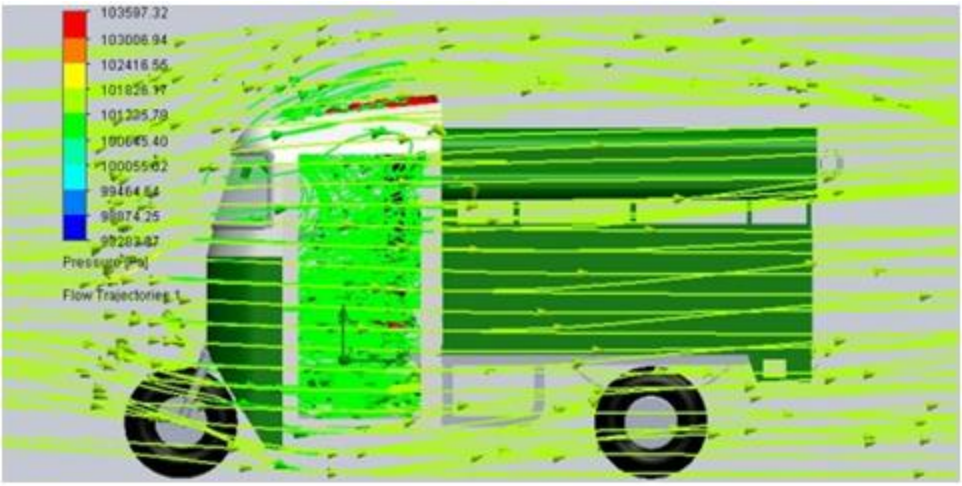

Figure 1:Pressure distribution of RFM 1 at the speed of 100km/h

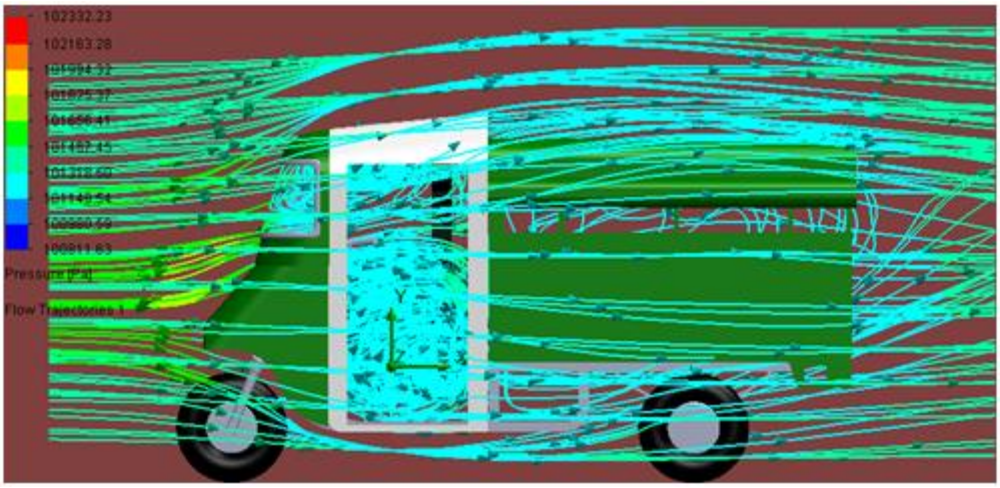

Figure 2: Pressure distribution of NASENI TC1 at 100km/h

Figure 1 and 2 shows the simulation and pressure result of RFM1 and NASENI TC1 respectively at the speed of 100km/h. The flow trajectory shows the movement of air molecules around the tricycles in the computational domain. Equation 2 and 3 were used to evaluate the fuel consumption and the power required in overcoming drag force for the two models respectively.

Furthermore, some necessary assumptions were made. These assumptions includes that the efficiency of transmission will be constant and therefore can be taken to be 0.95, the engine operates constantly in an acceleration mode, the specific fuel consumption of the engine is 800g/KWh and the density of fuel is 0.77Kg/L. These assumptions will be the same for both cases.

Considering the fact that the tricycle engine uses motor gasoline as its fuel, equation 4 was used to evaluate the rate of CO_2 emissions for the two models.

III. RESULT AND DISCUSSION

Table 2: Aerodynamic result for RFM 1

Drag force (N)	Area (m^2)	Speed (km/h)	Velocity (m/s)	ρ(kg/m2)	Cd
10.819	2.315	40	11.11	1.165	0.065
16.911	2.315	50	13.89	1.165	0.065
24.357	2.315	60	16.67	1.165	0.065
33.125	2.315	70	19.44	1.165	0.065
43.276	2.315	80	22.22	1.165	0.065
54.782	2.315	90	25.00	1.165	0.065
67.643	2.315	100	27.78	1.165	0.065

From tables 2 and 3, the coefficient of drag, C_d of RFM1 and NASENI TC1 is 0.065 and 0.055 respectively. This gives a percentage difference in the Cd from RFM 1to NASENI TC1 as 15.385%.

Table 4 shows the result analysis of power required to overcome drag force, fuel consumption and CO_2 emission rate for the two tricycles models at different speeds. At 100Km/h, the percentage difference of the of power required to overcome drag force, fuel consumption and CO_2 emission rate from RFM 1 to NASENI TC1 is 13.793%, 13.61% and 13.56% respectively.

Table 3: Aerodynamic analysis for NASENI TC1

Drag force (N)	Area (m^2)	Speed (km/h)	Velocity (m/s)	ρ(kg/m2)	Cd
9.352	2.365	40	11.11	1.165	0.055
14.618	2.365	50	13.89	1.165	0.055
21.055	2.365	60	16.67	1.165	0.055
28.634	2.365	70	19.44	1.165	0.055
37.409	2.365	80	22.22	1.165	0.055
47.355	2.365	90	25	1.165	0.055
58.473	2.365	100	27.78	1.165	0.055

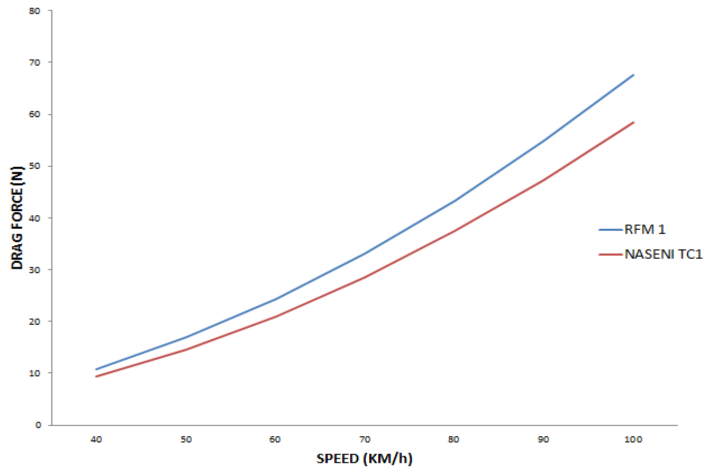

Figure 3: Drag force vs. Speed

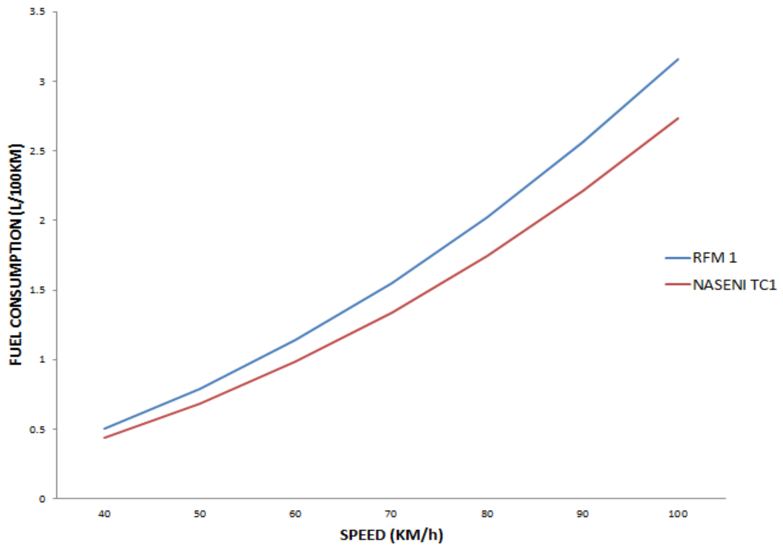

Figure 4: Fuel consumption vs. Speed

Table 4: Analysis of power, Fuel consumption and CO_2 emissions

Velocity (Km/h)	Power (KW)		Fuel consumption (L/100Km)		CO_2 emissions ($KgCO_2$/100Km)	
	RFM 1	NASENI TC1	RFM 1	NASENI TC1	RFM 1	NASENI TC1
40	0.1849	0.1599	0.5055	0.4372	1.4154	1.2242
50	0.3614	0.3124	0.7905	0.6833	2.2134	1.9132
60	0.6247	0.54	1.1387	0.9843	3.1884	2.756
70	0.9907	0.8564	1.5478	1.338	4.3338	3.7464
80	1.4794	1.2788	2.0224	1.7482	5.6627	4.895
90	2.107	1.8214	2.5603	2.2133	7.1688	6.1972
100	2.891	2.499	3.1617	2.733	8.8528	7.6524

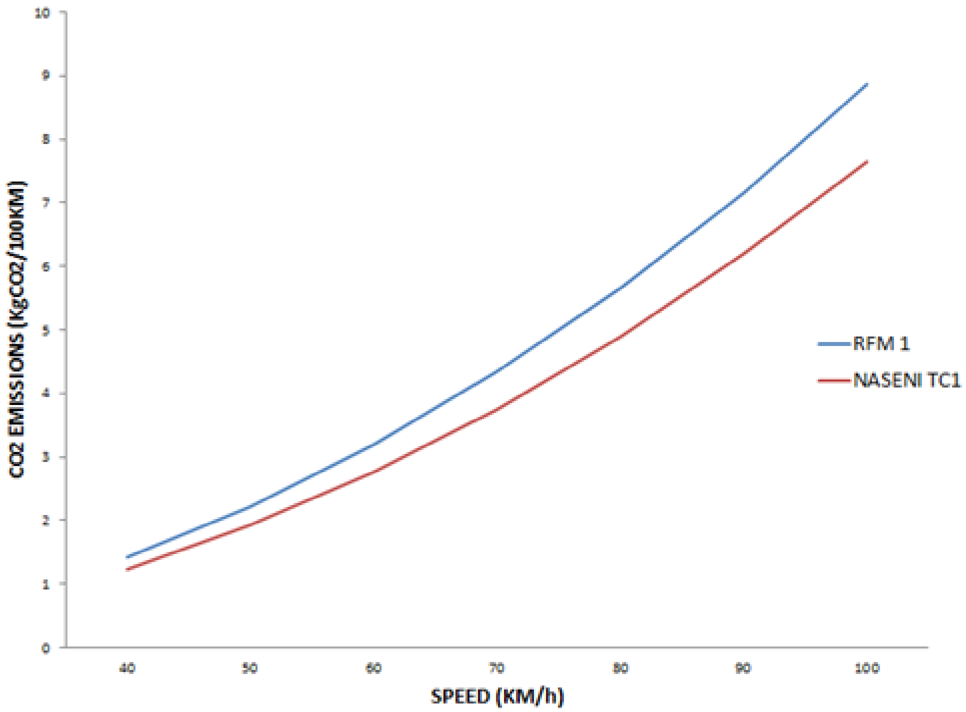

Figure 5: CO_2 emissions vs. Speed

Figure 3, 4 and 5 shows the plots of drag force, fuel consumption and rate of CO_2 emissions against speed respectively. It is deduced from the figures that the drag forces, fuel consumption and CO_2 emissions increases with an increase in speed. Secondly, NASENI TC1 has a reduced

Fuel consumption rate, reduced rate of CO_2 emissionsand reduced amount of driving power when compared to RFM 1.

Figure 6 and 7 shows the plots of CO_2 emission against fuel consumption for NASENI TC1 and RFM1 respectively. It is deduced from the plot that the rate of emission increases with increase in fuel consumptionfor the two models.Analysis on the power, fuel consumption and CO_2 emissions for the tricycle models show that NASENI TC1 uses less power to overcome drag force when compared to RFM1. Therefore, RFM1 will use more fuel and will pollute the atmosphere more than NASENI TC1

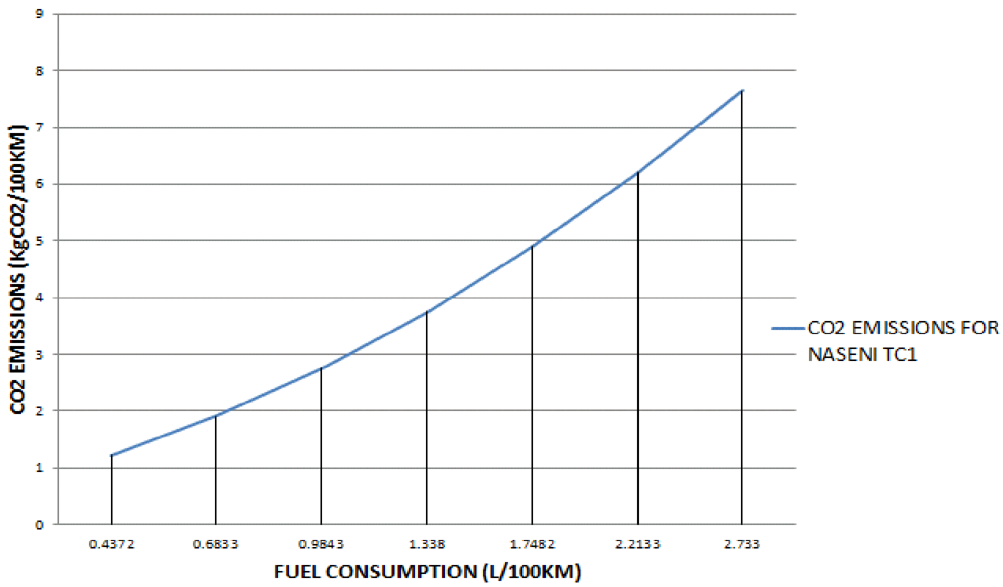

Figure 6: CO_2 emissions vs. Fuel consumption for NASENI TC1

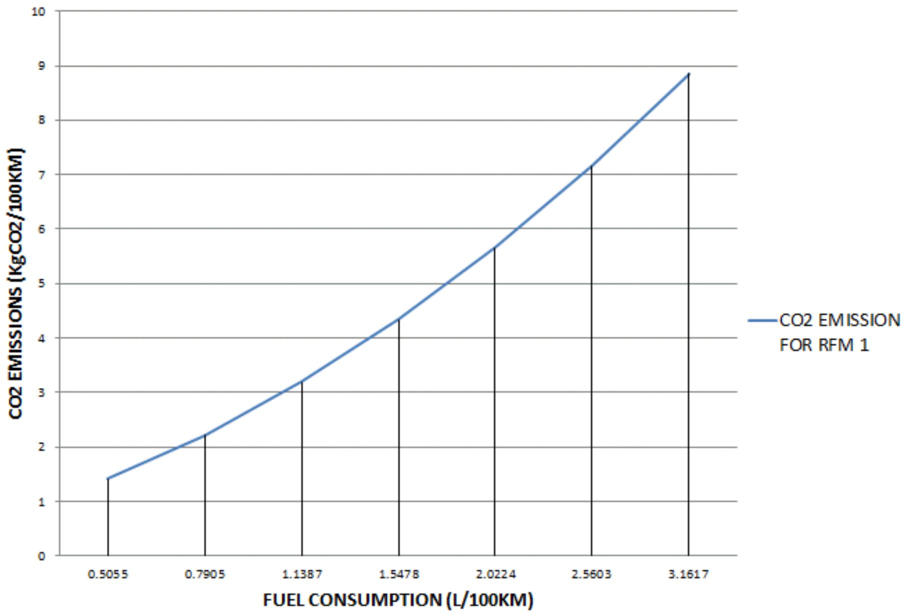

Figure 7: CO_2 emissions vs. Fuel consumption for RFM 1

IV. CONCLUSION

Study of fuel consumption and CO_2 emissions of cargo tricycles with reference to their body has been carried out.The Two tricycles were modeled, simulated for aerodynamics effects. The power required to overcome drag, Fuel consumption and CO_2 emissions was calculated. The results show that NASENI TC1 has a fuel consumption rate of 2.73L/100km and emits 7.65 $KgCO_2$/100Km while RFM1 consumes 3.16L/100km and emits 8.85$KgCO_2$/100Km.

This result shows that NASENI TC1 is more fuel efficient and emits lesser CO_2 when compared to RFM 1.

V. RECOMMENDATION

To reduce CO_2 emissions and fuel consumption to the required target in the transportation sector, it is recommended that;

- Vehicle body shape designs should be improved upon,
- Improve vehicle maintenance,
- Improve vehicle operation (eco-efficient driving) and
- Make use of energy sources with a lower carbon intensity during vehicle design.

VI. ACKNOLEDGEMENT

This project was supported by National Agency for Science and Engineering Infrastructure (NASENI) and National Engineering Design Development Institute (NEDDI).

REFRENCES

[1.] BusinessDictionary.com (2015).Fuel efficiency. Retrieved from http://www businessdictionary.com/definition/fuel-efficiency.html.
[2.] Wikipedia.org (2014) fuel efficiency. Retrieved from http://www.en.m.wikipedia.org/wiki/fuel_efficiency.
[3.] Wikipedia (2014, October 8). Fuel economy in automobiles. Retrieved from http://en.wikipedia.org/wiki/Fuel_economy _in_automobiles.
[4.] Totalmotocycle.com (2014). Best Scooter MPG Guide. Retrieved from http://www.totalmotorcycle.com/MotorcycleFuel EconomyGuide/best-scooter-MPG.htm.
[5.] Beststarmotor.com (2006).TW150ZH-2B (150CC/200CC Three Wheeler). Retrieved from http://www.bestarmotor.com/ product/GasolineThreeWheeler-TW150ZH-2B.html.
[6.] Michael R., Crumley J. (2007). Gas Mileage Dependence on Area and Drag Coefficient. Spring 1-6.
[7.] USEPA. (1994). National Air Quality and Emissions Trends Report, pp. 2, 6, 46, 52. United States Environmental Protection Agency, Washington, DC, USA
[8.] P.N. Ndoke, O. D. Jimoh (2005). Impact of Traffic Emission on Air Quality in a Developing City of Nigeria.*AU Journal*, 8 (4), 222-227.
[9.] Scientificamerican.com (2014). 2014 to Be Hottest Year Ever Measured. Retrieved from http://www.scientificamerican.com/ article/2014-to-be-hottest-year-ever-measured/.
[10.] Cline, W.R. 1991. Scientific basis for the greenhouse effect. *Econ. J*. 101, 904-919.
[11.] Susan A. S, Timothy E. L (2007) Reducing Greenhouse Emissions and Fuel Consumption. *IATSS RESEARCH*. vol.31 (1), 6-20.

[12.] USEPA. 1993. Guide to Environmental Issues, Doc. No. 520/B-94-01 United States Environmental Protection Agency, Washington, DC, USA.
[13.] USEPA. (2014). Sources of Greenhouse Gas Emissions. Retrieved from http://www.epa.gov/climatechange/ghgemissions/ sources.html.
[14.] L.Yu, D. Small (2003). Vehicle Emissions. *The UMAP Journal*, 24 (4), 451-472.
[15.] Michael B. C., Efraim S., Alon K. (2013) Analytical Modeling of Fuel Consumption. *Energies.* 6,117-127.
[16.] Ekuase A., Aduloju S.C, Ogenekaro P., Ebhota W.S., Dania D.E. (2015). Determination of Center of Gravity and Dynamic Stability Evaluation of a Cargo-type Tricycle. American Journal of Mechanical Engineering . 3(1), 26-31
[17.] Agarana D., Ekuase A., Odomagah E.S., Olah S., Dania D. (2015) . Aerodynamics Comparative Analysis of CargoTruck Tricycles. International Journal of Engineering and Technology. 5(6), 375-385
[18.] Metu C., Aduloju S.C., Bolarinwa G.O, OlenyiJ.,Dania D. E. (2014) Vehicle Body Shape Analysis of Tricycles for Reduction in Fuel consumption. *Innovative System Design and Engineering*. 5 (11), 91-100.
[19.] Silva, C., Ross, M., & Farias, T. (2009). Analysis and simulation of "low-cost" strategies to reduce fuel consumption and emissions in conventional gasoline light-duty vehicles. *Energy Conversion and Management*, 50(2), 215-222
[20.] Cefic and ECTA. Guidelines for Measuring and Managing CO2 Emission from Freight Transport Operations, 2011. *Cefic and ECTA*