GROSTLOG 2019
Global Research on Sustainable Transport & Logistics

ISSN: 2622-5778 (online)
Advances in Transportation and Logistics Research
http://proceedings.itltrisakti.ac.id/index.php/altr

Environment and Cost Analysis of using Compressed Natural Gas as Alternative Fuels in Jakarta

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Abstract. Compressed Natural Gas is one of the alternative to substitute Gasoline and Diesel with advantages of lower emission and lower cost to operate. Vast utilization of Natural Gas substituting Fossil Fuel would contribute to decrease Indonesia dependency on Oil. This study attempt to project the Green House Gases produced by certain fuel type (BD20, Gasoline or E10, and CNG) using WTW analysis with the help from GREET (Green House Gases, Regulated Emission, and Energy Use in Transportation) Model to demonstrate the emission produced by vehicles in Jakarta. To determine the cost efficiency, Return On Investment calculated by the data collected from Toyota Hilux 2,5 G CI engine with dual fuel converter with 60% CNG and 40% Biodiesel. In SI engine, the efficiency measured in cost saving per kilometer. The analysis shows that in Jakarta, Vehicle using CNG fuel produced the most Methane but the lowest amount of particulate matter. The cost calculation in Dual Fuel CI engine suggest that the more vehicle travels, and the less fuel economic it possess, it will emerge shorter period of ROI. Eventually, the main objective is to encourage more parties to start using CNG as well as government to facilitate the conversion process.

Keywords: alternative fuel, compressed natural gas, transportation, emission, pollution, vehicle, biodiesel

A. Introduction

Jakarta is the most polluted city in the world on June, 26th 2019 according to Air Visual (Table 1) [1] Most of the pollution are produced from the emission generated by Combustion Engine Vehicle and Industry. Combustion Engine vehicle produce approximately 71% of NOx, 15% of SOx, and 70 % of PM10. This should become a consideration for every party that participate in transportation industry [2]. In 2016, there are approximately 18.006.404 numbers of vehicle operating in Jakarta [3], which mainly utilize gasoline or diesel as its fuel. In fact, Gasoline or Diesel are not the best fuel since it produces enormous number of pollution fossil fuel contributes to large pollution is a huge problem. Both derivatives from the hydrocarbon fuel itself like carbon dioxides and impurities like heavy metals, sulfur, and uranium contribute to the pollution. [2] Beside, the national Oil reserve is also diminishing over a time which is not for too long. [4]

Table 1. World Air Quality Index and PM 2.5 air pollution

No.	Major City	US AQI
1	Jakarta, Indonesia	175
2	Dubai, United Arab Emirates	157
3	Delhi, India	149
4	Wuhan, China	140
5	Kathmandu, Nepal	132
6	Lahore, Pakistan	117

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7	Tashkent, Uzbekistan	110
8	Lima, Peru	110
9	Santiago, Chile	110
10	Beijing, China	110

Source (www.airvisual.com June 27, 2019)

Most of the pollution are produced from the emission generated by Combustion Engine Vehicle and Industry. Combustion Engine vehicle produce approximately 71% of NOx, 15% of SOx, and 70 % of PM10. This should become a consideration for every party that participate in transportation industry [5]. In 2016, there are approximately 18.006.404 numbers of vehicle operating in Jakarta, which mainly utilize gasoline or diesel as its fuel. Besides, the national Oil reserve is also diminishing over a time which is not for too long. [4]

Alternative are obligatory to be found, some fuel alternatives had been introduced such as LNG, propane, hydrogen, fuel cell and one of them is CNG (Compressed Natural Gas). CNG is considered as the most feasible alternative due to its clean nature of combustion and some other advantages which are; 1. wide availability 2. Eco friendly 3. Conventional SI and CI engine compatibility 4. Low Operational Cost [2] CNG has lower emission compared to the fossil fuel [6] Besides, the Natural Gas reserve is considerably abundance in Indonesia with approximately 7000 MMSCFD [7] CNG are produced from gas wells or tied in with crude oil production. The main composition of CNG is methane (CH4) with other composition within (ethane, propane, nitrogen, helium, carbon dioxide, hydrogen sulfide, and water vapor) Natural Gas then compressed and stored in very high pressure container about 200 bar. [6]

The application of CNG in vehicle engine is categorized by 4 types that utilize CNG as its Fuel Supply. Dedicated CNG Engine, which only operates on natural gas. Bi-fuel engine that retrofitting gasoline engine vehicle with converting kit to compatible running on Natural Gas. Dual Fuel Engine, this very type of engine work on Diesel, CNG, or even the mixture of both [2]. CNG engine offers Advantages both for the user and the environment Natural Gas due to its five advantages (1) It is the only fuel cheaper than gasoline or diesel. (2) It has inherently lower air pollution emissions. (3) It has lower greenhouse gas emissions. (4) Its use extends gasoline supplies [2] CNG seems to be the solution for all the problem relating to fuel and pollution occuring in Indonesia. But counterintuitively, there is no large scale utilization of CNG as vehicle fuel which depicted by the number of NGV (Natural Gas Vehicle) is only around 5,690 vehicle [8]

In this paper, the writers intend to compare the utilization of CNG to Fossil fuel in term of emission and cost-efficiency. The emission will be analyzed with WTW (Well to Wheel) Analysis. WTW analysis calculate the emission with every component produced by every type of fuel along its life cycle (from the mining process to the exhaust augmentation) which also known as Life Cycle Assesment.[9] The WTW analysis datas are obtained with the help of GREET Model.

GREET Model is a software developed by Argonne National Laboratory to evaluate various combination of vehicle and fuel on a complete vehicle cycle (Well to Wheel and Well to Pump). Then, the WTW number will be multiplied with the number of vehicle with considered type in Jakarta. The cost efficiency will shown as the calculation of cost saved per kilometer vehicle travel where the data are obtained from previous studies that used Toyota Hilux 2.5 G diesel engine displacement of 2.494 cc alongside the 17.4 : 1 Compression ratio. [10] Hopefully, the results shown will attract the eyes of transportation parties (Private car owner, Business parties, Etc).

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B. Methods

The method that this paper used is to find which fuels produce less emission and more economical to provide better air and less pollution in Jakarta. The methodology that used in this paper is Qualitative and the data and information is collected from previous researches and GREET Model. First step is to search the estimation of vehicle number in Jakarta especially distribution and passenger vehicle. Followed by Searching the Life Cycle Assesment of GHG (The GHG components are CO2, CH4, PM 10 and PM 2.5, SOx and NOx.) of the various fuels (CNG, BD20, Gasoline) from GREET model. And then estimates the GHG produced by vehicle by multiplying the number of each type of vehicle with the GHG amount. At last, comparative analysis done by comparing each GHG components.

The analysed GHG Components are CO_2 possess large impact to the environment. The most contributing source of CO_2 is the burning of fossil fuel while deforesation is the second. The current proportion of CO_2 in the air is at 400 ppm while 450 is high risk [11] CH_4 contribution to the total greenhouse effect is around 4% to 9 %. CH_4 is a heat-trapping gas higher than CO_2 [12] PM 10 and PM 2.5 are synonym with dust or described as fine particles. [13] SO_x and NO_x are pollutant produced by vehicle and other industrial activities. Its produce ozone [14]

In term of economic efficiency, the ROI (Return on Investment) is calculated for the diesel dual-fuel engine by calculating multiple components which are : Fuel Consumption : projected by various Fuel consumption per kilometer due to the fact that there are numerous factor involving in the fuel consumption; BioDiesel fuel cost : obtained by the Jakarta price of Biodiese which currently rating at Rp. 5.150;Dual fuel cost : which are the result of adding between the 40% price of the biodiesel and 60% of Natural Gas in Jakarta.; Fuel Cost per year : the fuel cost per year numbers are the result of multiplying the number of fuel used per 100 km with the number of kilometers travelled per year.; Saving per year : the saving amount is directly calculated by the expense gap between each fuel.; ROI period : eventually, the ROI period accounted by dividing the Installation Cost of Rp 30.558.600 with the saving per year.

C. Discussion And Result

Based on the GREET WTW analysis, the total emission of the estimated cars/light vehicles for the different vehicular fuel types considered is described in this section. GHG emissions from fossil fuels depend on both the carbon content of the fuel and process energy inputs.

Table 2. numbers of each component of GHG that produced from the total number of vehicle in Jakarta per kilometer each of them travelled.

Emission	CNG Trucks	CNG Cars	BD20	Gasoline
CO	9630491.673	16225390.11	876507.8827	15771533.04
NO_x	1187168.904	1815428.264	2019296.641	1588499.731
PM 10	5037146.566	5276088.392	7211773.719	11630087.32
PM 2.5	4216113.866	4254909.994	6102270.07	8453087.854
SOx	377231.2407	44818385.27	343946.1312	54519580.05
CH_4	12326585.54	7261713.056	1986011.532	2893338.796
CO_2	1453449780	1758696131	1819585984	2326017463

ISSN: 2622-5778 (online)
Advances in Transportation and Logistics Research
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1. emission produced by type of fuels and vehicles.

This section will describe and evaluate the estimated emission of each type of vehicle (Passenger car and Distribution Truck) with its fuel types (CNG, Biodiesel, and Gasoline) based on GREET WTW Analysis.

CH4 is most produced by CNG fueled vehicle both cars and truck due to its characteristic which mainly composed by CH4 (methane). CNG produces the lowest CO2 compared to Biodiesel and Gasoline in both cars and trucks, but CNG produces slightly higher amounts of SOx.

Sulphur dioxide are mostly produced by the industrial activity involving material thath contains sulphur (e.g the generation of electricity using coal) where transportation sector is not the major source of sulphur dioxide in air. NOx amounts are least produced from vehicle with CNG fuel while its most produced by truck fueled by Biodiesel. Particulate Matter 10 and 2.5 calculation result shows that CNG is the least Contributor while gasoline car rank the highest amount compared to the truck. PM10 and PM 2.5 have profound effect on health and environmental. PM10 and PM2.5 synonym as dust so it's the reason most metropolitan city air is not as clear as the remote area.

2. Cost Advantage of CNG Vehicle

From the data collected, it is known that the average consumption of SI engine using gasoline is 12km/l with the purchase and installation cost of converter kit approximately Rp.15.000.000. to obtain the average consumption of the engine using CNG, calorific value takes into the consideration. One litre of gasoline has the calorific value of 46.536 MJ/Kg and record the range of 12 km. CNG has bigger calorific value with 52.225 MJ/Kg which extent the range to 13.5 km. With the price of gasoline in Indonesia (Pertalite) which is Rp. 7.650, the vehicle will require approximately 9 litres of gasoline per 100 km travels that cost Rp 68.850 compared to the CNG fueled with 7.4 litre gasoline equivalent per a hundred kilometers which cost only Rp.22.940. the result shows that a converted SI engine will save around Rp. 45.910 or Rp 459 per kilometer.

Analyzing the ROI (Return on Investment) from an experimental trial of installing dual fuel converter kit to a 2.500cc Toyota Hilux engine with 60% use of CNG and 40% use of Biodiesel.

$$\$DF = 60\%\ CNG + 40\%\ Diesel$$

$$\$DF = dual\ fuel\ price$$

The fuel cost consumption is obtained by calculating the consumption with the fuel price per litre the unit is in L/km

$$CostD = FC \times \$BioDiesel$$

$$CostDF = FC \times \$DF$$

$$CostSAVE = CostD - CostDF$$

$$FC = fuel\ consumption$$

$$\$Diesel = biodiesel\ price.$$

The saving cost per year is calculated by multiplying the saving cost from biodiesel and CNG and the average distance per year.

$$Saving/year = CostSAVE \times \delta ANNUAL$$

$$\delta ANNUAL = average\ travel\ distance\ per\ year$$

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The result will used followingly. To discover the ROI of installation, installation cost is divided by the saving cost per year

$$ROI = \frac{Installation\ Cost}{Saving/year}$$

At the moment this paper was written, the price of biodiesel in Indonesia is Rp.5150 and the price of CNG of Rp 3.100 (jabodetabek)

Table 3

Fuel Consumption (L/100km)	Diesel Fuel Cost (Rp/100km)	Dual Fuel Cost (rp/100km)	based on travelling about 25000 km				based on travelling about 50000 km				based on travelling about 75000 km			
			Diesel Cost/Year (Rp)	Dual Fuel Cost/Year (Rp)	Saving per Year (Rp)	Periode ROI (Year)	Diesel Cost/Year (Rp)	Dual Fuel Cost/Year (Rp)	Saving per Year (Rp)	Periode ROI (Year)	Diesel Cost/Year (Rp)	Dual Fuel Cost/Year (Rp)	Saving per Year (Rp)	Periode ROI (Year)
7.5	38625	29400	Rp9,656,250	Rp7,350,000	Rp2,306,250	13.25034	Rp19,312,500	Rp14,700,000	Rp4,612,500	6.625171	Rp28,968,750	22050000	Rp6,918,750	4.41678
7.9	40685	30968	Rp10,171,250	Rp7,742,000	Rp2,429,250	12.57944	Rp20,342,500	Rp15,484,000	Rp4,858,500	6.289719	Rp30,513,750	23226000	Rp7,287,750	4.193146
8	41200	31360	Rp10,300,000	Rp7,840,000	Rp2,460,000	12.4222	Rp20,600,000	Rp15,680,000	Rp4,920,000	6.211098	Rp30,900,000	23520000	Rp7,380,000	4.140732
8.5	43775	33320	Rp10,943,750	Rp8,330,000	Rp2,613,750	11.69148	Rp21,887,500	Rp16,660,000	Rp5,227,500	5.845739	Rp32,831,250	24990000	Rp7,841,250	3.897159
8.9	45835	34888	Rp11,458,750	Rp8,722,000	Rp2,736,750	11.16602	Rp22,917,500	Rp17,444,000	Rp5,473,500	5.583009	Rp34,376,250	26166000	Rp8,210,250	3.722006
9	46350	35280	Rp11,587,500	Rp8,820,000	Rp2,767,500	11.04195	Rp23,175,000	Rp17,640,000	Rp5,535,000	5.520976	Rp34,762,500	26460000	Rp8,302,500	3.68065
9.5	48925	37240	Rp12,231,250	Rp9,310,000	Rp2,921,250	10.4608	Rp24,462,500	Rp18,620,000	Rp5,842,500	5.230398	Rp36,693,750	27930000	Rp8,763,750	3.486932
9.9	50985	38808	Rp12,746,250	Rp9,702,000	Rp3,044,250	10.03814	Rp25,492,500	Rp19,404,000	Rp6,088,500	5.019069	Rp38,238,750	29106000	Rp9,132,750	3.346046
10	51500	39200	Rp12,875,000	Rp9,800,000	Rp3,075,000	9.937756	Rp25,750,000	Rp19,600,000	Rp6,150,000	4.968878	Rp38,625,000	29400000	Rp9,225,000	3.312585
105	540750	411600	Rp135,187,500	Rp102,900,000	Rp32,287,500	0.946453	Rp270,375,000	Rp205,800,000	Rp64,575,000	0.473226	Rp405,562,500	3.09E+08	Rp96,862,500	0.315484
10.9	56135	42728	Rp14,033,750	Rp10,682,000	Rp3,351,750	9.117207	Rp28,067,500	Rp21,364,000	Rp6,703,500	4.558604	Rp42,101,250	32046000	Rp10,055,250	3.039069
11	56650	43120	Rp14,162,500	Rp10,780,000	Rp3,382,500	9.034324	Rp28,325,000	Rp21,560,000	Rp6,765,000	4.517162	Rp42,487,500	32340000	Rp10,147,500	3.011441
11.5	59225	45080	Rp14,806,250	Rp11,270,000	Rp3,536,250	8.641527	Rp29,612,500	Rp22,540,000	Rp7,072,500	4.320764	Rp44,418,750	33810000	Rp10,608,750	2.880509

As shown in **Table 3**, the shortest period of ROI are achieved by the highest ranking fuel consumption of 11.5 litres per a hundred kilometres and the vehicle that travels in the longest distance per year of 75.000km with the ROI period of 2,8 years compared to the vehicle that consume 7.5 litres per a hundred kilometers with the yearly travel of 25.000 km that takes 13 years to achieve ROI. Thence, the more fuel consumed and more range travelled by a vehicle will bring shorter period of ROI.

D. Conclusion

Jakarta air quality has proven to be in bad condition and waiting to become severe as the time goes, as the population grow, and as the demand of energy increase. There is no entity that own the ability to decrease the demand of energy because everything is growing bigger and bigger thing that plausible to improve the air quality which is by decreasing the impact. Engine combustion powered by fossil fuel proven to contribute a large number of air pollution especially particulate matters. CNG as the fuel alternatives produce lower emission and particulate matter.

The utilization of CNG on vehicle hopefully will bring profound virtue to the human health and environment. Moreover, CNG fuel in vehicle requires less cost to operate due to the lower price. Conventional engine could be converted to CNG engine with some adjusment that is still waiting for more research so eventually it will meet its maximum efficiency. Lower cost means higher profits for those who utilize the vehicle for business activity such as trucking and distribution companies.

To encourage more and more participant to convert from Fossil Fuel to CNG fuel, the Indonesian government needs to build reliable numbers of infrastructure of refilling station, and considering to allocate the subsidy from fossil fuel to natural gas. These have to be done before

ISSN: 2622-5778 (online)
Advances in Transportation and Logistics Research
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fossil fuel price is too expensive to afford and Indonesia still predominantly depends on Fossil fuel and before the air is not even safe to breathe.

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