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IMPACT OF ADOPTING DIESEL-CNG DUAL-FUEL ENGINE ON HAULAGE

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ABSTRACT

Climate change brought about by the emission of Greenhouse Gases (GHG) has shone a spotlight on the role of the internal combustion engine. These engines are significant contributors to GHG emissions. However, there have been recent improvements in their design. Natural gas produces lower GHG emissions during combustion, making it suitable as a fuel in internal combustion engines. Aside from the emission impact of gasoline and diesel, the collapse of Nigeria's petroleum refineries has impacted the availability of the products and caused them to have exorbitant prices for the populace. The country is, however, richly blessed with natural gas, which is waiting to be tapped and put to use. The conversion of a fleet of diesel trucks by a local haulage company will have both financial and GHG emissions impacts. This study investigates these impacts. By the fifty-third month, the investment starts to yield dividends, which accrue to over $34,000 over the useful life of each truck. Also, for each converted truck there is a reduction in GHG emissions of around 13.22 tons annually.

Contribution/Originality: This study brings to light the potential gains of using diesel-CNG dual-fuel engines for goods haulage in terms of greenhouse gas emission reduction and cost savings and serves as a template for the adoption of this technology.

1. INTRODUCTION

The concept of dual-fuel engines is as old as the innovation of the compression ignition engine, as demonstrated by Rudolf Diesel. There is a growing interest in the use of dual-fuel engines to mitigate the relatively high emission levels associated with the use of conventional fuels (Barba, Dyckmans, Förster, & Schnekenburger, 2017; Igbojionu, Anyadiegwu, Anyanwu, Obah, & Muonagor, 2019). The low emission levels are in addition to the relatively lower operating costs; the price of diesel is about ten times that of natural gas per unit of energy release (Bullis, 2013). The adoption of a dual-fuel engine retains the fundamental principles of the compression ignition engine's operation, indicating a relatively unchanged efficiency (Redtenbacher et al., 2018), though it has been shown to drop by about 2.1% in some cases (Fasching, Sprenger, & Granitz, 2017). However, the operation is no longer entirely based on compression ignition as the pilot diesel fuel serves as the igniter for the compressed gas fuel (Wei & Geng, 2016). A dual-fuel engine is thus an internal combustion engine in which the primary fuel is homogenously mixed with air, as in a spark-ignition engine, and ignited by a pilot diesel fuel at high pressure as in a compression ignition engine.

Locomotives that run on dual fuels are in operation, and trucking companies are also adopting its usage, primarily to minimize running expenses. Dual fuel engines allow for a reversal to 100% diesel fuel when the situation warrants it. The dual-fuel engine suffers a performance/emission advantage loss at low and intermediate loads (Ashok, Ashok, & Kumar, 2015; Fasching et al., 2017; Wei & Geng, 2016) that is characteristic of light diesel engines utilized for transportation. However, mitigation is possible with the adoption of a control system (Bullis, 2013) that can sense the load and make the appropriate adjustment to the gas to diesel ratio, as well as the adoption of the dual direct injection concept (Fasching et al., 2017). The solution to low load challenges is to use a glow plug in the combustion chamber (Vijayabalan & Nagarajan, 2009). The efficiency of a dual-fuel engine does surpass that of a diesel engine at high loads (Aydin, Irgin, & Celik, 2018; Senthamaraikkannan, Chakrabarti, & Prasad, 2014; Vijayabalan & Nagarajan, 2009) making it preferable for use in such times. The typical gas to diesel ratio in a dual-fuel engine is about eighty percent; higher fractions can have a significant impact on engine performance, primarily due to the low cetane number of gas (Bullis, 2013; Senthamaraikkannan et al., 2014; Tira, Herreros, Tsolakis, & Wyszynski, 2012). However, advances in technology are helping to push the fraction further. The gases are better suited for use in spark-ignition engines because of their high octane number (Ashok et al., 2015; Tira et al., 2012).

The relative ease of converting diesel engines to dual-fuel mode, coupled with the twin advantages of cleaner combustion (Ashok et al., 2015; Barba et al., 2017; Boretti, 2019; Bullis, 2013; Igbojionu et al., 2019; Senthamaraikkannan et al., 2014; Towoju & Dare, 2016; Towoju & Dare, 2018; Towoju & Dare, 2018; Wei & Geng, 2016) and reduced operating expenses, is encouraging consumers to opt for its adoption. The required infrastructure for natural gas refueling stations, however, is still an impediment. The primary fuel in dual-fuel engines is a matter of choice and availability, although each has its pros and cons. While Liquefied Natural Gas (LNG) is more cost-effective in terms of storage and energy density (Boretti, 2019), its production cost is higher than that of Compressed Natural Gas (CNG) and it poses more refueling difficulties. Liquid Petroleum Gas (LPG) boasts an equivalent weight-to-mileage ratio to gasoline and increases engine longevity (Adegoriola & Suleiman, 2020), but it emits more carbon IV oxide gas.

With the seemingly comparatively carbon IV oxide emission rates of Electric Vehicles (EVs) and Internal Combustion Engine Vehicles (ICEVs) (Towoju & Ishola, 2020; Towoju, 2021) coupled with EVs' mileage and recharge challenges (Towoju & Dare, 2018), the diesel engine is on course to maintain its importance in the immediate future. The carbon IV oxide emissions of diesel engines are lower than those of gasoline engines (Towoju & Ishola, 2020). However, they suffer from high emission levels of Nitrogen Oxides (NOx) and Particulate Matter (PM) (Towoju & Dare, 2016).

Nigeria's petroleum downstream sector is faced with daunting challenges of inefficiencies, a reason for the government to call for the increased adoption of gaseous fuels. However, this could be a blessing in disguise. While LNG is better suited to heavy-duty haulage trucks because of its high volumetric energy density, the need for a cryogenic system poses a challenge (Boretti, 2019). Pressurized tanks are, however, less daunting, making the adoption of CNG-diesel dual engines in a country like Nigeria more plausible. This study seeks to quantify the expected impact of the conversion of a fleet of four thousand (4,000) haulage trucks by a Nigerian haulage company from diesel to CNG-diesel dual-fuel engines – not just the financial impact on the company but also how it would contribute to a greener environment. Section II examines the impact the adoption of diesel-CNG dual fuel will have in economic terms, and Section III examines its impact on gas emissions. The final section presents the conclusions of the paper.

2. COST IMPACTS

First, the average fuel mileage of the fleet of trucks operated by the company under consideration is established. For a 30-tonne truck, this is about 2.02 km per liter of Automotive Gas Oil (AGO), which is consistent with the average for large trucks weighing over 15,000 kg, a figure that stands at about 2.28 km per liter of AGO (Fuel Efficiency, 2013). The truck engine specification is depicted in Table 1. By convention, CNG for automobile use is maintained at a pressure of 3600 psi and is sold either as Gasoline Gallon Equivalent (GGE) or Diesel Liter Equivalent (DLE). The DLE is calculated as the volume of the alternative fuel that will produce the equivalent energy of a liter of diesel.

Table 1. Truck engine specifications.

Parameter	Details
Type	4-Stroke direct injection diesel engine, turbocharging with inter-cooling
Compression ratio	17:1
Displacement	9.726 L
Cooling system	Water cooling
Bore/Stroke	126mm/130mm
Compressor type	Twin-cylinder

The GGE is related to the diesel equivalent through the equation:

$$GGE = 1.155 \; x \; Diesel \; gallon \qquad (1)$$

Equation 1 presents the relation employed to derive the Gasoline Gallon equivalent of diesel.

The Nigerian government proposes a CNG price of ninety-seven (97) Naira for a liter equivalent of gasoline. Hence the cost of CNG's DLE is derived using the expression presented in Equation 2:

$$CNG_{DLEP} = 1.155 \; x \; CNG_P \qquad (2)$$

in which CNG_{DLEP} is the CNG diesel liter equivalent price, CNG_P is the price of a CNG liter equivalent of gasoline.

$CNG_{DLEP} = 1.155 \, x \, 97$ = 112.04 (Naira).

The specific scenario studied in this paper is the journey from Ibese in Ogun State to Yenogoa in Bayelsa State, Nigeria. With a distance of 603 km, there is a monthly target of six (6) return trips. The average daily distance covered by a truck is calculated with the expression in Equation 3;

$$D_{avg} = \frac{12(H_D x \, T_N)}{365} \quad (3)$$

D_{avg} is the average daily distance, H_D is the haulage distance, and T_N is the number of trips covered monthly.

H_D = 2 x 603 = 1206 km

$D_{avg} = \frac{12(1206 \, x \; 6)}{365}$ = 238 km.

With a truck's daily average travel distance of 238 km, the daily fuel consumption is determined using Equation 4:

$$DF_c = \frac{D_{avg}}{M_l} \quad (4)$$

Equation 4 relates the average daily travel distance to the mileage per liter of fuel.

DF_c is the daily fuel consumption per truck, M_l is the mileage per liter of DLE (km/liter).

$DF_c = \frac{238}{2.02}$ = 117.82 DLE

The cost of converting a heavy-duty truck to diesel-CNG dual fuel hovers around £15,000 (Clark, 2018). In Naira, this is equivalent to about 7,386,900 at an exchange rate of 492.46 to a pound sterling. This is a high upfront cost, and it is expected to be sourced through a commercial loan and repaid gradually with the savings in fuel costs. Working with the general conservative mix ratio of 1:1 for diesel-CNG fuel, the daily consumption of CNG by a truck is derived using Equation 5:

$$CNG_c = \frac{DF_c}{2} \quad (5)$$

$CNG_c = \frac{117.82}{2}$ = 58.91 DLE

The daily cost savings realized with the use of CNG to replace AGO is evaluated using Equation 6:

$$S_c = \; (AGO_{ex} x \, AGO_p) - (CNG_{DLEP} x CNG_c) \quad (6)$$

S_c is the cost savings, AGO_{ex} is the quantity of replaced AGO, and AGO_p is the price of a liter of AGO and is equal to 224.43 (Naira).

$S_c = (58.91 \, x \, 224.43) - (112.04 \, x \, 58.91)$ = 6,620.89 (Naira).

Using an average loan rate of 16% per annum as applicable in Nigeria, Figure 1 depicts the time at which a break-even point will be reached such that afterward the cost of conversion will be offset.

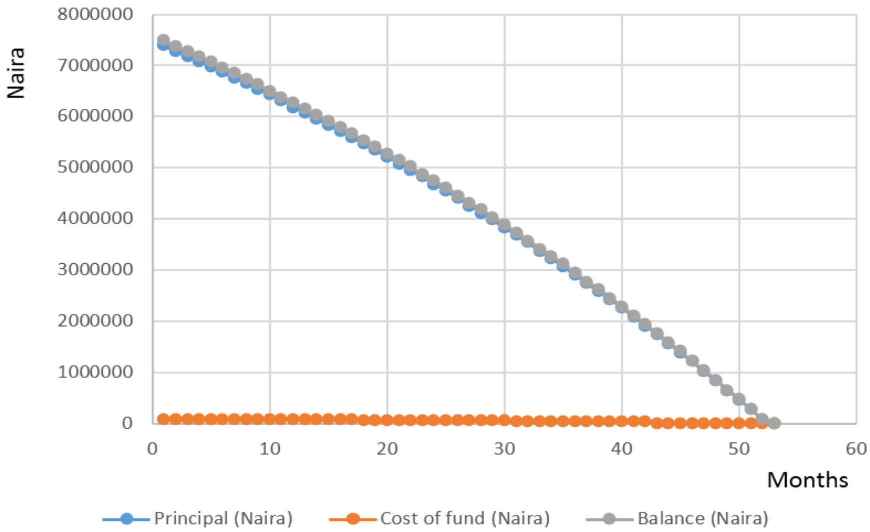

Figure 1. Break-even point for truck conversion.

The cost savings of the fuel will offset the capital investment after fifty-three (53) months, and the subsequent life of the truck will result in investable funds. With an expected lifetime of a hundred and twenty (120) months, a savings of over thirteen (13) million Naira could be realized. The conversion of a fleet of four thousand (4,000) trucks by the haulage company will thus result in a savings of over fifty-two (52) billion Naira, that is, about a hundred and thirty-six (136) million dollars at an exchange rate of 381.44 to a dollar over the expected useful life of the trucks.

3. EMISSION IMPACT

It is an indisputable fact that compression ignition engines powered with AGO are sources of nitric oxides (NOx) and particulates, aside from the other greenhouse gases (GHG) (Towoju & Dare, 2016; Towoju & Dare, 2018; Towoju & Dare, 2018). Looking beyond the expected financial gains of adopting diesel-CNG dual-fuel engines, this section seeks to quantify the expected impact on emission reduction. Table 2 depicts the carbon IV oxide, methane, and nitride emission rates for heavy-duty vehicles using the transport fuels under study, AGO and CNG.

Table 2. Transport fuel emission rates.

Fuel	CO_2 (kg/DLE)	CH_4 (g/DLE)	N_2O (g/DLE)
CNG	1.815	11.9140	1.06051
AGO	2.677	0.00644	0.00606

Data source: (Emission Factors from Cross Sector Tools, 2017; US EPA Climate Leaders, 2016).

Figure 2 depicts the CO_2 emissions of a truck over a thirty (30) day period using AGO and CNG/AGO in a 50:50 ratio as fuel. N_2O and CH_4 have a more potent effect on the environment. N_20 emissions are three hundred (300) fold those of CO_2, while CH_4 emissions are about twenty (20) fold those of CO_2 (US EPA Climate Leaders, 2016). Figure 3 depicts the resultant GHG generated by a truck fueled with AGO and the dual fuel, taking the contributions of N_2O and CH_4 into consideration.

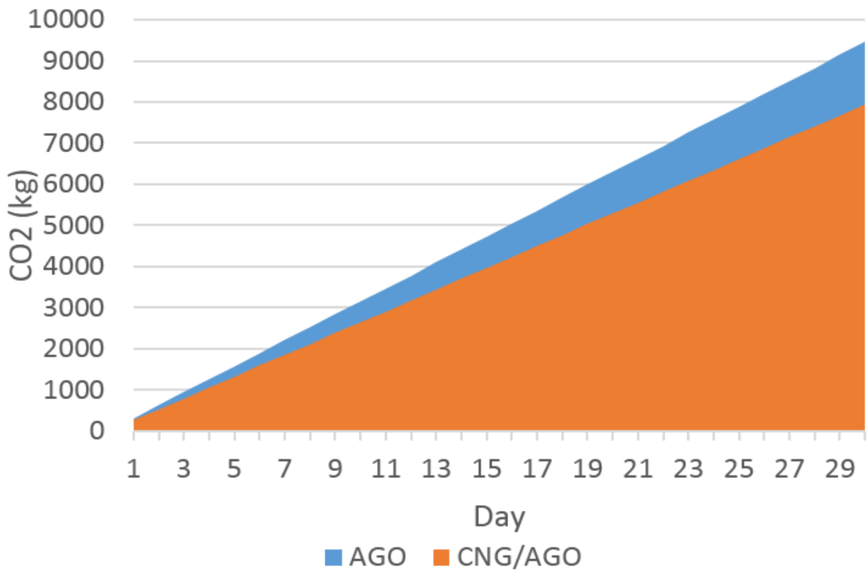

Figure 2. CO_2 emissions over a 30-day period.

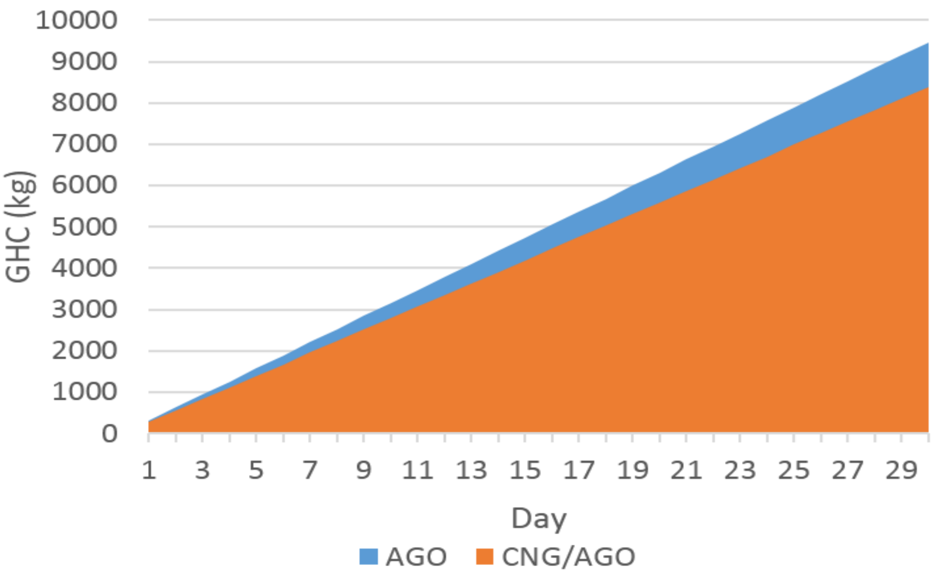

Figure 3. Average GHG emissions over a 30-day period.

The conversion of the considered diesel truck to a diesel-CNG dual-fuel engine results in a reduction of GHG emissions. The data from Figure 2 shows a reduction in GHG emissions amounting to 1,086.96 kg by the end of 30 days, which connotes an annual reduction of 13.22 tons. The conversion of a fleet of four thousand (4,000) trucks by the haulage company will thus bring about a reduction of about 52,880 tons of GHG emissions annually, compared to the sole use of AGO fuel.

It was assumed that each of the trucks in the fleet travels the same distance daily and that the data used to compute the price of fuel and the emission values remain unchanged over the useful life of the trucks. Variations in the price of the fuels, emission characteristics, average daily mileage, and the cost of the conversion process can lead to different results from those documented in this study.

4. CONCLUSION

The adoption of the diesel-CNG dual-fuel engine by haulage companies will contribute significantly to their profit margin and will also assist in making our environment greener. The conversion of a single truck will lead to a cost savings of about $34,000 on fuel over its useful life and a reduction in GHG emissions of around 13.22 tons annually.

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