A Techno-economic Assessment of Diesel to Gas Power Plant Conversion

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Abstract

Diesel is the main fuel for use in industrial, transport, and in diesel power plants; unfortunately, it is polluting and non-renewable. This study proposes conversion of a 120 MW diesel engine power plant is converted to a natural gas-powered plant with the objective of reducing emissions and cost of power by avoiding and reducing generation from heavy fuel oil. The study showed that the use of natural gas simultaneously reduces the cost of generation per kWh and emissions, particularly SO_X. The conversion process involves modification of the fuel injection system to cope with new fuel injection and ignition requirements, new control for fuel injection and reduced air to fuel ratio and lowering of the engines' compression ratios through increase of the engine cylinder clearance volume. These fuel savings will influence renegotiation of the power purchase agreement resulting into lower tariffs, higher load factor and power plant utilization which translates to more revenue and reduced unit cost of power with lower environmental impact as well as better return on investment from the largest grid connected diesel power plant in East and Central Africa. This study showed that dual fuel diesel power plants running on both natural gas and diesel exhibit better performance indicators in terms of engine specific fuel consumption, engine brake thermal efficiency, diesel engine indicated thermal efficiency, the power plant electricity generating unit cost of power, the total engine emissions and hence leading to less environmental impact. Therefore, the engine fuel conversion will reduce the cost of power and emissions.

Key Words

Diesel power plants, internal combustion engines; diesel to gas engine conversion; fossil fuel power plants; natural gas power plants.

1. Introduction

Diesel is the main fuel for use in many industrial, transport, and in diesel power plants. However, it is polluting and non-renewable (Arefin et al., 2020). Hence, there is a dual need to reduce emissions and cost of power from diesel engine power plants (Niemi, 1997). The current trend of using diesel fuel has a negative impact to consumers in terms of high electricity tariffs (Andae, 2017).The environmental impact of diesel power plants includes emission of So_x, NO_X emissions and oil spills and leakages to the environment (Barasa, 2020; Jeremiah, 2018). The emissions also react with the ozone layer leading to its depletion. The greenhouse gases are responsible for the global warming in addition to other health effects to humans like chronic respiratory diseases, lung cancer, heart diseases, and damage to brain, liver and kidneys. On average basis, it costs ksh. 6.00 (6 US cents) to produce 1 kWh of electricity using natural gas (Eurostat, 2020) which is much lower compared to diesel power generation which costs about ksh. 30 (US cents 30) (Andae, 2017; Kabeyi & Olanrewaju, 2020b). Therefore, conversion to natural gas will reduce the cost of power generation.

As an alternative fuel, natural gas can be produced by purification of biogas, also called bio methanation. Natural gas is also abundant in supply, is cleaner and cheaper than diesel (Arefin et al., 2020). Conversion to dual-fuel engines also called diesel dual fuel has an added advantage over full conversion to natural gas since they can run on either natural gas or diesel when either of the fuels is unavailable. Additionally, natural gas is clean and leads to 20% to 30% reduction in CO_2 emissions, 70% to 90% reduction in CO emissions and generally 50% to 87% reduction in NOx emissions (Shasby, 2004). In this conversion approach, the engine compression ratio is maintained high and hence the engine performance is retained upon conversion (Kabeyi, 2019). Another benefit is the additional degree of freedom needed to control combustion like the homogeneous charge compression ignition (HCCI) and the partly premixed compression ignition (PPCI). This means reduction in pollution tariffs and less impact on environment. Converting the existing diesel engines through modification costs less than doing overhaul of the plant (Königsson, 2014). In many countries around the world, there is growing interest in converting diesel power plants mainly to increase energy security and reduce cost of unit power (Engineering Research Center of Engineering innovation, 2014). Engine modification and proper use of natural gas can lead to better system efficiency, reduction in greenhouse gas emissions and lower electricity costs leading to competitive economies and a cleaner environment for humanity (Kabeyi & Olanrewaju, 2020a).

2. Diesel Power Generation

2.1. Introduction to diesel power plants

Diesel electric power plants vary in sizes for application in central, decentralized, and off grid power generation. They have a wide range of applications which include peak load plants, mobile plants, standby units, emergency plants, nursery plants, black start plants and central power plants (Agrawal, 2006; Kabeyi & Olanrewaju, 2020b; Rajput, 2009).

2.2. Diesel Engine Power Plant Design and Construction

Diesel electric power plants vary in sizes for application in centralized, decentralized, and off grid power generation(Kabeyi & Oludolapo, 2020a, 2021). The power plants have a wide range of applications which include use as peak load plants, mobile power plants in various field applications, standby power plant units, emergency power plants, nursery plants, black start plants and central power plants (Agrawal, 2006; Kabeyi & Olanrewaju, 2020b; Rajput, 2009). Diesel engines work on the principle of the diesel thermodynamic cycle which consists of four processes completed in either two or four stroked of the pistons. Most diesel engine power plants use four stroke diesel engines(Kabeyi & Olanrewaju, 2020b). Most diesel engine power plants use four stroke diesel engines. The four strokes that constitute a complete cycle four stroke engine combustion are the suction/Intake, compression, power, and exhaust strokes take place the combustion chamber. These events are completed within two complete cycle s of the crankshaft(Kabeyi & Oludolapo, 2020a, 2020d)

The main components of a diesel power plant includes, the engine, fuel supply system, air intake system, exhaust system, cooling system, lubricating system, engine starting system and governing and control system (Rajput, 2009). A diesel engine can either be four-stroke or two-stroke. Four-stroke engines are mostly used due to their higher efficiency and are more balanced. In diesel engines, air is compressed adiabatically in the cylinder elevating the temperature of air before atomized fuel is injected to the combustion chamber. The high temperature caused by air compression ignites the diesel fuel spontaneously. The products of combustion expand pushing the piston downward which then drives the crankshaft setting the engine into operations(Agrawal, 2006).

Natural gas engines are either bi-fuel or dedicated natural gas engines. The bi-fuel engines run on natural gas or gasoline, and they work on the Otto cycle which is used by spark ignition engines. These engines maintain both natural gas and gasoline fuel supply systems which makes them flexible and efficient. The dedicated natural gas engines also work on the Otto cycle, hence are spark ignited engines fueled by natural gas as the only fuel source(M. Kabeyi & O. Olanrewaju, 2022; M. J. B. Kabeyi & A. O. Olanrewaju, 2022; Kabeyi & Oludolapo, 2020b). The dedicated natural gas engines are optimized in terms of compression ratio to take the benefit of high octane rating of natural gas (Group of Experts on Pollution & Energy (GRPE), 2001). Unlike the bi-fuel engines which are based on the Otto cycle, the dual fuel natural gas engines are based on the diesel cycle technology, which is the operating cycle for diesel engines, but they use natural gas as the primary fuel. The dual engines are designed to operate smoothly with diesel interchangeably mainly a 'pilot' ignition source. The dual fuel engines can also operate on 100% diesel fuel especially when they are idling or on low loads. These engines admit more natural gas as the load increases usually to 80% or more natural gas. The benefits of natural gas use in dual and bi-fuel engines is better fuel economy and cleaner combustion with lower emissions (Group of Experts on Pollution & Energy (GRPE), 2001).

2.3. Natural Gas Fuel for diesel power plants

Natural gas mainly consists of methane (CH_4) and trace amounts of ethane, propane, nitrogen, helium, hydrogen sulfide, carbon oxide and water vapor. The principal component is methane which is normally above 90% (Shasby, 2004). A natural gas engine is a mechanical engine that uses natural gas as a fuel to produce power (mechanical or electrical). There are three natural gas engine options namely; spark-ignition reciprocating internal combustion engine, gas-fired turbines and dual fuel gas engines.

The main features which make natural gas attractive as a fuel for power generation and hence increased interest in its application are; wide availability, environmental friendliness, compatibility with the conventional spark ignition and compression ignition engine and low operational cost compared to other fossil fuels (Khan et al., 2015). The advantages of natural gas power plants include efficient combustion, low cost, complies with environmental regulations, high availability and supply, cleaner power.

2.4. Composition of compressed natural gas

Compressed natural gas has the following typical properties which may be slightly different from the uncompressed natural gas. These properties are summarized in Table 1 below.

Table 1. Typical composition of compressed natural gas in Vol% (Munde & Dalu, 2012).

	Element	Symbol/Formulae	Volumetric %
1	Methane	CH_4	94.42
2	Ethane	C_2H_6	2.27
3	Propane	C_3H_8	0.03
4	Butane	C_4H_{10}	0.25
5	Nitrogen	N_2	0.44
6	Carbon dioxide	CO_2	0.57
7	Others	-	2.00
	Total		100%

From table 1, it is noted that CNG as a fuel is a mixture of several organic gases with the highest component being methane. Other common constituents of CNG are ethane, butane, propane, Nitrogen, and carbon dioxide.

2.5. Converting Diesel engines to gas engines

Dual-fuel operations need modification to facilitate gas injection into the combustion chamber through the inlet manifold. To initiate gas ignition requires the fuel injector to inject pilot diesel into the compressed gas/air mixture. The configuration of the fuel injector nozzle is also selected to match fuel delivery rate, the form of spray as well as pressure of injection (Robert Bosch GmbH, 2021). A diesel engine can be converted to a full gas engine but requires several modifications and changes (Mitzlaff, 1988). They include the following changes, Removal of the injector pump and injection nozzles,

2.6. Conversion of Diesel Engine to Dual-Fuel Engine

The main components and systems to be modified are; the fuel Injection System, fuel gas system, air and Exhaust System, Combustion Chamber and Control System (Engineering Research Center of Engineering innovation, 2014). For gas diesel engines, the electric efficiency varies with the power required for gas compression. A gas diesel (GD) engine like the Wärtsilä V46GD can realize optimum shaft efficiency of 49.6% in gas operation at about 85% to 90% loading. Energy consumed during compression is about 2.5% shaft power output, for inlet pressure of 16 bar. However, if the gas is delivered in liquefied form, the compression work consumes about 0.8% of shaft power output. In another case, at the gas-driven Ringgold Cogen power station, the plant heat rate is about 9,300 kJ/kWh which corresponds to an efficiency of around 39% with plant availability of about 90.1% after over 48 months of operation (O'Keefe, 1995). The gas diesel engines of the plant run on natural gas compressed to 250 bars for injection with pilot oil amount of about 5% of fuel intake. The power plant has specific lubricating oil consumption averages about 0.8 g/kWh (Niemi, 1997).The main challenge with gas engine is that the NOx emissions level is higher. As a result of this; in a natural gas engine, a catalytic exhaust purification system may be necessary to reduce the NOx emissions from a level of 1300 mg/MJ(fuel) to a target level of 200 mg/MJ as it is in an existing plant in Finland which emits from small gas turbines plant (Niemi, 1997).

Since natural gas is the cleanest fossil fuel, it can be used in many applications to reduce the negative environmental impact of fossil fuel combustion. The use of natural gas in power generation reduces cases of fog since it leads to less NOx emissions which is the main cause of smog. Acid rain whose principal sources SO_2 and NO_x is also reduced by use of natural gas in place of oil and coal since natural gas emits almost no SO_2 and emits up to 80% less NOx than coal(Weber et al., 2000). A shift from coal and oil to natural gas will significantly reduce pollution from power plants since power generation is a leader in greenhouse gas emissions, example in 2002, power generation accounted for 67% of Sulphur dioxide emissions, 40% of CO_2 emissions, 25% of NOx emissions, and 34% of mercury emissions in the US because coal fired power plants have a significant contribution to generation capacity. It can also be noted that natural gas combined cycle power plant emit about 50% as much CO_2 as modern super critical coal power plant(NaturalGas.org, 2013).

Whereas liquefied natural gas (LNG) as a fuel has got lower carbon per unit energy compared to diesel and heavy fuel oil, its use might not reduce greenhouse gas emissions on a life-cycle basis. A study by (Sui et al., 2020) analyzed the life-cycle GHG emissions of marine gas oil (MGO), liquefied natural ga (LNG), low sulfur industrial diesel fuel, and heavy fuel oil in internal combustion engines suitable for international application and found out that over a 100 year basis the maximum life cycle greenhouse gas emission reduction by use of LNG is 15% compared to marine gas oil (MGO) but if a high pressure dual fuel (HPDF) injection is used as well as upstream methane emissions. The control of upstream methane leaks is however not easy which further reduces the benefit of using LNG in place of diesel. The situation is worse if natural gas is derived from shale gas as this is bound to lead to more upstream leakages. The analysis based on a 20-year GWP showed some 4% more life cycle GHG emissions from LNG compared to MGO when upstream leakages are considered. The study also showed that technology choice has a significant impact on the lifecycle emissions from LNG. For example, use of LNG leads to about 70% more life-cycle GHGs emissions when LNG is used in place of MGO and about 82% more than MGO when used in medium-speed diesel engines(MSD) engine(Pavlenko et al., 2020).

A shift to natural gas will also lead to more use of shale resources which have significant water requirement. This may put pressure on water resource use and water pollution in the process of natural gas recovery. Water used in natural gas extraction is wastewater and needs treatment on the positive side, although natural gas production consumes water, the demand is considerably less water per unit of energy delivered compared to coal production, manufacture of ethanol production, tar (oil) sands, or oil shale. All the same, natural gas production from shale resources needs more water than conventional natural gas production and hence more demand for natural gas will lead to increased demand and use of water from available resources. (Pavlenko et al., 2020).

3. Materials and Methods

Natural gas engines differ in the ignition methods, range of the air-fuel ratio, compression ratio, and which influence performance and emissions characteristics. With its high-octane rating, natural gas allows an increase in power for Otto cycle engines. As a gas, natural gas needs a larger volume in the engine combustion cylinder than diesel and other liquid fuels, which will effectively reduce power output of the engine. To compensate for this volume requirements, natural gas needs to be stored and used in compressed form. Even in compressed form, the storage space remains higher for natural gas compared to diesel and other liquid fuels(Werpy et al., 2010). Conversion from diesel to natural gas requires design and construction of gas storage, handling, and supply systems. Engine compression ratios may also need some adjustment and in some applications, there is need for exhaust gas treatment to limit NOx emissions.

This study targeted the largest diesel power plant in East and Central Africa, namely Kipevu III 120 MW power plant which is equipped with 7 Wärtsilä W18V46 of capacity 17.1 MW running on heavy fuel oil. The engine specifications

3.1. Methods and Procedure

For a successful conversion of a diesel engine power plant to a dual-fuel natural gas the following procedure is applied:

i. Obtain existing design specifications of the diesel engine.
ii. Modification and addition of parts of the engine.
iii. Reduction of the compression ratio.
iv. Identify the appropriate Gas Storage and Gas Supply System.
v. Draw a layout design of the Dual-Fuel Power Plant.

3.2. Overview of the Design

In the design of a dual-fuel engine power plant, the following modifications and additions need to be done on the existing diesel power plant:

3.3. Modification of the Fuel Injection System

For successful conversion of the injection system, a D-GID® Electronic Control Unit is introduced just before the natural gas and diesel are injected into the engine. The D-GID® system is the first technological platform developed by Ecomotive Solutions. Innovative system allowing the fuel diesel engines with a mixture of diesel oil and natural gas (CNG compressed natural gas, LNG liquefied natural gas, Bio methane, Syngas, etc.). D-GID® Control Unit determines the amount of diesel fuel injected and air/gas mixture dosage dynamically, modifying it in real time according to the feedback provided by the engine to guarantee perfect operational conditions (Kumar & Gaddipati, 2017).

3.3. Reduction of the Compression Ratio

Natural gas requires lower compression ratio compared to diesel, therefore a modification to facilitate this is required. A plate is added between the piston head and the cylinder block and act as a seal between the engine block and the piston head which increases the clearance volume. The shape of the plate will follow the shape of the top of the piston head (Kumar & Gaddipati, 2017). This plate is a gasket plate that normally exists in every engine block and acts as a seal between the piston head and the engine block.

Natural gas with compression ratio lower than diesel requires modification in the cylinder to facilitate this is required. A plate is added between the piston head and the cylinder block and acts as a seal between the engine block and the piston head which increases the clearance volume. The shape of the plate will follow the shape of the top of the piston head. The plate is a gasket plate that normally exists in every engine block and acts as a seal between the piston head and the engine block (Kumar & Gaddipati, 2017; Li, 2004). Therefore, addition of gasket plate is needed for the purpose of this project to increase the clearance volume An additional gasket was introduced. Effectively reducing the clearance height.

For one cylinder:

Swept volume $Vs = \frac{\pi \times b^2 \times l}{4}$

b- bore diameter.

l- stroke length

V_c- Clearance volume

Compression ratio $C.R = \frac{Vs+Vc}{Vc}$

Additional plate creates an extra volume V_{plate}

$$V_{plate} = \frac{\pi}{4} \times b^2 \times t$$

Where t – plate thickness

$$\text{The new } C.R = \frac{V_s + V_c + V_{plate}}{V_c + V_{plate}}$$

3.4. Gas Piping and Supply System

A gas supply system is required to supply natural gas from storage tank to the dual-fuel engine (Arefin et al., 2020; Boretti, 2020; Kumar & Gaddipati, 2017). It includes: an industrial gas filter, a pressure regulator, a gas shut-off valve and pipes.

3.5. Gas Storage System

Natural gas can be stored as CNG (Compressed Natural Gas) or LNG (Liquefied Natural Gas). LNG takes up about 1/600th the volume of natural gas in the gaseous state. The liquefaction process involves removal of certain components, such as dust, acid gases, helium, water, and heavy hydrocarbons. The natural gas is condensed into a liquid as low as close to atmospheric pressure by cooling to approximately -162^{o}C and maximum pressure around 25kPa. The choice of the storage tanks depends on the consumption rate of the fuel. When dealing with large volumes, it is easier and convenient to store natural gas as a liquid. When selecting LNG tanks, other equipment must be accounted for. This is due to the process of regasification of LNG, which converts LNG from liquid state to gaseous state using a heat exchanger using ambient air or sea water. This equipment includes an LNG pump, vaporizer, and a compressor. On the other hand, in selecting CNG tanks, the most important parameter is the storage pressure(M. Kabeyi & O. Olanrewaju, 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022a).

3.6. Conversion of injection system

For conversion of the injection system, a D-GID® Electronic Control Unit, as shown in Figure 3 is proposed just before the natural gas and diesel are injected into the engine. The D-GID® system is the first technological platform developed by Ecomotive Solutions. The system facilitates a mixture of diesel oil and natural gas (CNG compressed natural gas, LNG liquefied natural gas, Biomethane, Syngas, etc.) injection to the engine cylinder. D-GID® Control Unit determines the amount of diesel fuel injected and air/gas mixture dosage by dynamically modifying it in real time according to the feedback provided by the engine to guarantee perfect operational conditions (Ecomotive Solutions S.r.l, 2020a, 2020b).

D-GID® manages and controls the quantity of diesel fuel injected, which is reduced up to 80-90% (in steady conditions). The average substitution rate in dynamic working conditions is 40-50%. D-GID® substitution rate strategy aims at keeping the engine performance unvaried, although variations could technically be set for specific needs.

3.7. Converted system.

Figure 1 below illustrates the proposed dual diesel-CNG system for conversion of the diesel power plant to dual fuel power plant.

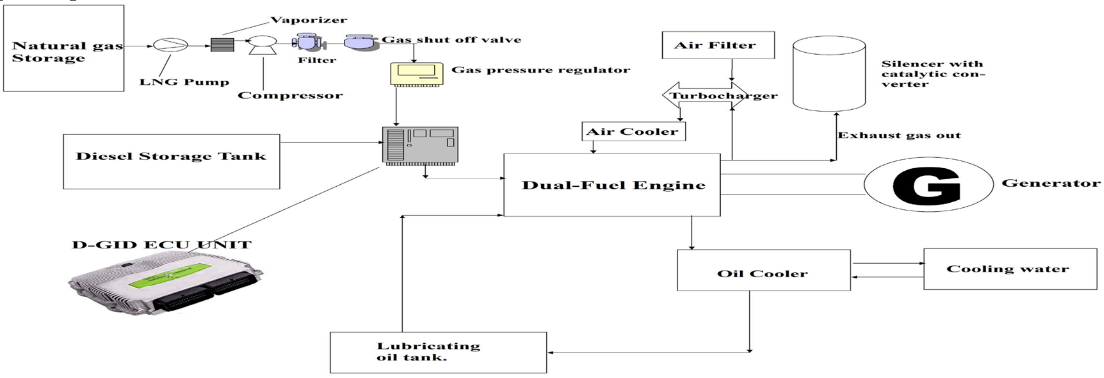

Fig. 1. The Dual fuel system.

From figure 1 above, the main elements of the proposed system are the D-Gid ECU unit, natural gas storage and handling facilities, and engine prime mover with all the necessary systems charge air system, fuel system, generator, engine units, and cooling system.

4. Results and Discussion

4.1. Parameters before and after conversion

Table 2 highlights the before and after conversion of the parameters

Table 2. Parameters before and after conversion.

Parameter	Before Conversion	After Conversion
Compression ratio	22:1	17.1
Specific fuel consumption	3400kg/h	2878.72kg/h
Fuel cost per hour	Ksh 186,190.474	Ksh 134,164.12
Load factor	0.5	0.5
Cost of fuel per kWh	Ksh 10.95	Ksh 7.89

From table 2, it is noted that the conversion involves reduced compression ratio from 22:1 to 17:1, the specific fuel consumption reduced by 15.3% and fuel cost per unit reduced by 27.9% while load factor was maintained at 0.5 for the purpose of performance analysis.

4.2. Cost Analysis

Table 3 informs the cost analysis and the payback period when the fuel savings and time are considered.

Table 3. Cost Analysis Table.

ITEM	COST (ksh)
Total Cost of Investment	153,492,500.00
Annual Fuel Cost Savings	453,407,867.60

Payback Period	4.06 Months

From table 3, it is noted that the estimated cost of the conversion is ksh 153, 492, 500 (US$ 15, 354,925) while annual fuel saving is based on proposed design is about ksh 453, 407, 867.60 (US$ 45,340,787), hence a payback period of 4.06 months for the estimated direct costs. Actual costs are however expected to be higher and can be established during detailed project design and analysis.

4.2. Discussion

It is noted from this study that a dual fuel diesel engine runs on both gas and diesel or heavy fuel oil. Natural gas is a cleaner fuel than diesel and heavy fuel. Although natural gas is nonrenewable, it can be substituted with biogas and biomethane which are renewable sources of energy with similar properties, especially biomethane. This study further established that natural gas produces the least total emissions compares to other fossil fuels followed by oil and coal respectively. Emissions coming from natural gas combustion include nitrogen oxides (NOx), carbon monoxide (CO), and carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), volatile organic compounds (VOCs), and trace amounts of sulfur dioxide (SO_2), and particulate matter (PM). Comparatively, natural gas produces 82.7% less total emissions than coal and 44.4% less total emission than oil. Since natural gas is the cleanest fossil fuel, it can be used in many applications to reduce the negative environmental impact of fossil fuel combustion(Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022b; Kabeyi & Oludolapo, 2020c).

The use of natural gas in power plants in place of diesel and coal, reduces cases of fog since it leads to less NOx emissions which is the main cause of smog. Acid rain whose principal sources SO_2 and NOx is also reduced by use of natural gas in place of oil and coal since natural gas emits almost no SO_2 and emits up to 80% less NOx than coal. Because of the clean combustion properties, natural gas use in power generation and transport has increased in countries like the US. Whereas it is not in dispute that natural gas as a fuel yield less emissions compared to diesel, there are legitimate concerns about natural gas leakages during handling and combustion given that methane is a more potent greenhouse gas, and this leads to uncertainty over the actual extent of the climate benefits from the use of natural gas as a fuel substitute to diesel power generation. Natural gas has high hydrogen/carbon (H/C) ratio compared to the other fossil fuels sources of energy which implies that CO_2 emissions are significantly lower while the mass per unit energy is also lower hence leads to lower specific fuel consumption. Additionally, combustion of natural gas leads to formation of water vapor and carbon dioxide as main products. These products have less environmental impact hence more preference for natural gas as a fuel(Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022; M. J. B. K. Kabeyi & O. A. Olanrewaju, 2022)

For diesel engines to run on both natural gas and diesel, the compression ratio must be reduced by increasing the engine cylinder clearance volume. It is easier to convert a diesel engine to a dual fuel engine relatively easily because the engine doesn't need changes on compression ratio, engine cylinder heads, or basic engine operation. The converted diesel engines are easier to install, operate and maintain. Two thicknesses of 10 mm and 5 mm were proposed for analysis, which gave compression ratios of 13.4 and 17.1, respectively. For a dual-fuel engine, a compression ratio of 16-18 is required. Therefore, the 5 mm thickness is chosen for the engine modification. The specific fuel consumption (sfc) of Kipevu III is 3400 kg/hr assuming full load optimum conditions. From this sfc, for one engine unit the cost of diesel fuel is calculated per hour. A diesel to natural gas ratio of 1:4 is chosen in our conversion. This ratio reduces the amount of diesel fuel used significantly and replacing it with natural gas. Natural gas has a higher calorific value of 52,000 kJ/kg compared to diesel 42,000 kJ/kg, which means it takes less natural gas to produce same power with diesel. With more natural gas displacement of diesel at the rate of 1 to 4, a cleaner combustion is expected and less unit cost of generation per unit power output.

The total cost of the dual fuel is calculated based on assumed average diesel cost of ksh 46/liter (US$0.46/liter) of oil and natural gas cost of $605/ton. Using a diesel/natural gas ratio of 1:4, the diesel sfc reduces to 640kg/h from 3400kg/h and the sfc of natural gas is 2196.72kg/h. The total sfc reduces to 2,836.72kg/h of natural gas based on the analytical calorific value of 52,000 kJ/kg of natural gas with average cost of natural gas taken as $605/ton. This fuel combination leads to lower cost of the dual fuel compared to the cost of diesel oil when used alone. For the 7 engines, a total of ksh 453,407,867.60 (US$ 4,534,079.00) can be realized in fuel cost savings at average load factor of 0.5. Considering all the additions to the existing design and all costs incurred during conversion, the total direct cost of investment amounts to ksh 153,492,500.00 (US$ 1, 534,925.00). The actual project cost is expected to be more than this value, however this estimated direct cost shows that the investment makes economic and financial sense as the payback on estimated direct cost is just 4.06 months. More accurate figures can be established by carrying out a detailed design and feasibility study for the project.

Based on global warming potential, methane stores more heat than carbon dioxide per unit of mass although it stays in the atmosphere for a shorter time. One ton of methane is equivalent to between 84 to 87 tons of CO2 based on a 20-year timeframe (GWP20) and between 28 and 36 tons on basis of 100-year timeframe (GWP100). The benefit of conversion of natural gas to electricity is that the conversion efficiency is higher than that for coal and diesel hence emission yield is lower for natural gas in terms of electricity produced instead of heat. All generation scenarios show that gas produces fewer greenhouse-gas emissions than coal and oil when generating heat or electricity, regardless of the timeframe considered(Gould & McGlade, 2017; Kabeyi & Oludolapo, 2020a).

Natural gas is the cleanest fossil fuel compared to coal and oil. Coal and oil consist of complex molecules with higher carbon ratios and higher composition of pollutant forming sulfur and nitrogen compared with natural gas. These leads to higher emissions of sulfur dioxide and nitrogen oxides (NOx) in addition to ash. On the other hand, natural gas produces minimal amounts of sulfur dioxide, nitrogen oxides and almost no ash or particulate matter and emits lower levels of carbon dioxide (CO_2), carbon monoxide (CO) and other reactive hydrocarbons. This makes natural gas an environmentally superior fossil fuel compared to coal and oil(Gould & McGlade, 2017; NaturalGas.org, 2013). Table 4 below shows the emission levels from natural gas, oil, and coal.

Table 4: fossil fuel emissions (pounds/per Billion Btu of energy output(NaturalGas.org, 2013)

	Pollutant	Natural gas	Oil	Coal	Remarks
1	Carbon dioxide	117,000	164,000	208,000	Natural gas has least CO2 emissions
2	Carbon monoxide	40	33	208	Oil produces least CO emissions
3	Nitrogen oxides	92	448	457	Natural gas emits the least amounts of nitrogen oxides
4	Sulfur dioxide	1	1,122	2,591	Natural gas emits insignificant amount of sulfur dioxide
5	Particulates	7	84	2,744	Natural gas emits negligible amounts of particulates
6	Mercury	0.000	0.007	0.016	Natural gas does not emit mercury to the environment
7	Total emissions	117,140	165,687	214,000	

From table 4 above, it is noted that between natural gas, oil and coal, natural gas produces the least total emissions followed by oil and coal respectively. It produces 82.7% less total emissions than coal and 44.4% less total emission than oil.

Using natural gas in power generation reduces cases of fog since NOx emissions are the main cause of smog. Acid rain whose principal sources SO_2 and NOx is also reduced by use of natural gas as a substitute fuel for coal and diesel. It can also be noted that natural gas combined cycle power plant emit about 50% as much CO_2 as modern super critical coal power plant(NaturalGas.org, 2013). However, if natural gas is derived from shale gas as this is bound to lead to more upstream leakages. The analysis based on a 20-year GWP showed some 4% more life cycle GHG emissions from LNG compared to MGO when upstream leakages are considered. The study also showed that technology choice has a significant impact on the lifecycle emissions from LNG. For example, use of LNG leads to about 70% more life-cycle GHGs emissions when LNG is used in place of MGO and about 82% more than MGO when used in medium-speed diesel engines(MSD) engine(Pavlenko et al., 2020). Additionally, natural gas production from shale resources needs more water than conventional natural gas production and hence more demand for natural gas will lead to increased demand and use of water from available resources.

Therefore, conversion from diesel to natural gas as a fuel has threats and opportunities as well as advantages and disadvantages. The short-term benefits are clear, but we have long term risks to the sustainable energy transition with respect to methane related environmental risks and delay in the transition to zero carbon economy and energy mix.

5. Conclusions

Conversion of diesel engine power plant to dual fuel diesel power plant using both natural gas and diesel has better performance indicators in terms of specific fuel consumption, brake thermal efficiency, indicated thermal efficiency, unit cost of generated power and total emissions and hence less environmental impact. Therefore, conversion will reduce the cost of electricity generation and amount of pollutants associated with diesel in power generation. The conversion will also lead better return on investment of the plant because of reduction in fuel related costs. Conversion from diesel fuel powered engines to full gas and dual fuel (gas and diesel) is both technically and financially feasible. Partial conversion to dual fuel mode is faster, cheaper, and more feasible as it requires less modifications and allows for more fuel diversity. The main engine modification done was reduction in compression ratio. The conversion will reduce specific fuel consumption reduces by 523.28 kg/h which will lead to reduction in the cost of fuel and related environmental impact. The main challenge of conversion of an existing facility is generation interruption and extra investment in storage and handling infrastructure for gas and the need to renegotiate the existing power purchase agreement. The long impact on the energy transition is delay in the achievement of zero carbon emissions. And the risk of creating transition related carbon lock-in and stranded assets by developing natural gas infrastructure during the global energy transition.

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