A Review and Evaluation of Alternative Fuel Sources for Transportation in Nigeria

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ABSTRACT- Alternative fuels have been the current focus of attention of many researchers as a result of the adverse effects fossil fuel has on the environment and the fluctuating crude oil prices. Many nations are therefore moving from conventional fuel sources to more non-conventional and sustainable fuel sources. Due to technological advancement, alternative fuels such as ethanol, hydrogen, electricity, biodiesel and natural gas have become the bane of fossil derived fuel.

According to the United States Environmental Protection Agency (EPA), 29% of Greenhouse gas emissions are generated from the transportation sector. Greenhouse gas emissions from transportation predominantly come from burning fossil fuel for cars, buses, ships and planes. Over 90% of fuel used for transportation is petroleum based which includes primarily Premium Motor Spirit (PMS) and Diesel. To reduce the amount of emissions generated by the transportation sector, serious importance has to be given to implementing other non - conventional fuels in this sector.

This paper evaluates different alternative fuels using a Multi-Criteria Decision Making (MCDM) tool; Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), taking cognizance of the economic, environmental and safety factors with respect to each fuel source. The research required input from both experts in the academia and industry to obtain a balanced point of view. Based on the findings, the various alternative fuel sources were prioritized in the order of importance in Nigeria as follows; biodiesel, compressed natural gas, ethanol, electricity and hydrogen. The implementation of alternative fuels in the transportation sector would contribute in reinventing the oil and gas sector to withstand the 'new energy future'.

Keywords: Alternative Fuel, Biodiesel, Electricity, Ethanol, Hydrogen, MCDM

1. INTRODUCTION

Since the dawn of the industrial age, fossil fuels have played a vital role in man's technological advancement especially in the provision of energy for various sectors necessary for living. According to Zhang (1), transportation is the largest consumer of the world oil, taking about 60% of the crude oil and 20% of CO2 emissions are from this sector. Due to the negative environmental impacts caused by the harmful emissions from the use of fossil fuels, the need to investigate alternative fuel sources is of paramount importance.

Alternative fuel sources are materials and substances that can be used as fuel but derived from other sources than petroleum. In modern times there have been numerous studies which shows that there are quite a number of alternative fuels. Hallet & Hamilton (2) called them "Potential New Liquid Fuels" and categorized them as follows;

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i. Gaseous Fuels: Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG), Hydrogen, Propane and Butane
ii. Alcohols: Ethanol, Methanol, Alcohol-Gasoline Blends
iii. Conventional Fuel Equivalent: Derived Diesel Fuel (Biodiesel)
iv. Others: Electric and Electric Hybrid Vehicles

Nigeria is one of the most populated nations in the world with an estimated population of 198 million people **Invalid source specified.**. The number of registered vehicles in Nigeria is estimated to be 11.7 million (3) out of which 38.6% are privately owned, 1.1% for government purposes and 60.3% for commercial use. Owing to such a huge number of vehicles, it stands to reason that a change from fossil fuels to alternative fuels will greatly reduce the amount of harmful emissions released to the atmosphere.

The focus of this paper therefore, is to review five fuel types: Electricity, Hydrogen, Compressed Natural Gas, Ethanol and Biodiesel, to ascertain their relevance to the Nigerian economy. Also, an evaluation of the most prepared alternative fuel using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), a Multi-Criteria Decision Making MCDM method, was attempted. This was to aid in proffering solutions for the selection of the best alternative fuel sources in this era of global challenges arising from the use of fossil fuel.

2. A REVIEW OF ALTERNATIVE FUELS

2.1 Natural Gas

Natural Gas is a clean burning form of fossil fuel that is found in underground reservoir rocks either on its own (non-associated gas) or in association with crude oil (associated gas) (4). Nigeria holds the tenth largest natural

gas reserve in the world with more than 5.2 trillion cubic meters and the first in Africa, making us one of the key players in the gas market. Natural gas resources are more evenly distributed than oil resources (5). Natural gas has been used for domestic household purposes for many years but it has recently gained notice as a source of fuel for powering vehicles.

Natural Vehicle Cars include; Audi A4, BMW E36, Honda Civic GX, Kia Pride, Suzuki SX4 etc. The biggest advantages of natural gas are its clean burning characteristics and its affordability. The engines are also cleaner and more efficient which results to longer service life and savings on maintenance costs. The major drawback of CNG vehicles is that, it is still a fossil fuel so the supply will eventually diminish.

In Nigeria, the Nigerian Independent Petroleum Company (NIPCO) Plc, an indigenous downstream petroleum and gas operator, has stated that there are over 5,000 vehicles that run on compressed natural gas, although a greater number is used for commercial purposes. (6). The company reviewed that the CNG powered vehicles had come to stay in Nigeria and the cost of converting petrol vehicles to CNG in Nigeria ranges from ₦200, 000 to ₦300, 000.

2.2 Hydrogen Fuel

Hydrogen is the simplest and lightest gas. It is found in water, organic compounds, biomass and hydrocarbons such as petrol, natural gas, methanol and propane. Hydrogen has high energy contents, it contains 120.7 kilojoules/gram, and this is the highest energy content per unit mass among known fuels. When burnt, hydrogen produces water as by-products and is therefore not only an efficient energy carrier, it is also very environment friendly (7).

It is possible to use hydrogen in internal combustion engines, directly or mixed with diesel and compressed natural gas (CNG). Hydrogen can also be used directly as a fuel in fuel cells to produce electricity to power cars. Hydrogen is often mentioned as a potential solution for several challenges that global energy system is facing (7).

Although hydrogen in theory has a major potential in solving the several problems in the global energy system, there are a few hitches which have to be addressed before they can be implemented in a developing nation like Nigeria. They are:

i. Availability of such Vehicles: Presently there are only three car manufacturers that produce commercial hydrogen vehicles; Toyota (Toyota Mirai), Honda (Honda Clarity FCV) and Hyundai (Hyundai Nexo) and they are only found in USA and Japan.
ii. High Cost of Vehicles: The cost of the vehicles is very high $60,000 which is equivalent to N22,000,000
iii. High Cost of Refilling Pumps: The cost of Hydrogen refilling pumps is also very expensive; a pump costs up to $1.5million which translates to billions of Naira.

According to Ankit, Ashish, Mahajani, & Mahadevan (8), Hydrogen possesses some characteristics which makes it suitable as a vehicle fuel, they are:

i. Wide range of flammability
ii. Small Quenching Distance
iii. High Flame Speed
iv. High Rate of Diffusion
v. Low Density
vi. Minimum Ignition Source Energy.

There are various ways in which hydrogen can be produced, they include:

i. Electrolysis (water splitting) process
ii. Coal refining
iii. Naphtha from crude oil
iv. Biogas Gasification
v. Hydrogen from biomass
vi. Natural gas refining

However, the two most common ways are; Electrolyzing water and Refining from fossil fuels (coal and natural gas). Electrolyzing water produces no direct emissions but the process requires a huge amount of energy and it also requires a substantial amount of water. Refining Coal and Natural Gas on the other hand requires less energy and incurs less cost, but the process produces higher emissions than petrol.

Hydrogen is not yet a perfect solution due to the high cost of the vehicle and its fuelling infrastructure, but it is a viable option because it provides enough range, power and is also environmentally friendly. If more research and resources go into its development and more car manufacturers invest in it, it would be a very viable option for the replacement of petrol vehicles in Nigeria.

2.3 Ethanol

Ethanol is a renewable fuel made from corn, soybeans and other plant materials. According to US Department of Energy, the use of ethanol is very common and more than 98% of gasoline (petrol) contains some ethanol. The use of ethanol as petrol additive is most commonly used at levels around 10% (E10) (9). The levels can be higher as much as 85% but these are obtained in special vehicles called Flexible Fuel Vehicle (FFV). FFV or Dual Fuel Vehicles are alternative fuel vehicles with an internal combustion engine designed to run on more than one fuel, usually gasoline blended with ethanol and both fuels are stored in the same storage tank (10).

Most petrol cars today can run on a blend of E10 without making any specifications. The number of FFV on the other hand is about 21 million in the United States alone with models such as GMC Yukon, Chevrolet Impala, Ford Taurus, Nissan Frontier and so on. The energy content of ethanol is lower than that of petrol therefore resulting in lower fuel economy but it has the advantage of improved efficiency and reduction in emissions (11).

The major drawback on production of Ethanol in Nigeria as a source of vehicle fuel is the negative impact it would have on food prices and availability.

2.4 Electricity

Electricity is used as alternative fuel either as battery powered vehicles or fuel cell vehicles. Battery powered vehicles store power in batteries that are recharged by plugging in the vehicle to a standard electrical source. Fuel cell vehicles on the electricity produced through an electrochemical reaction that occurs when hydrogen and oxygen are combined (12).

Electricity for transportation is already very popular in many countries. Many car manufacturers have models which run on electricity, some of them include; Audi e-tron, Ford Focus Electric, Nissan Leaf, Volkswagen e-Golf, Kia Soul EV, Hyundai Ioniq Electric etc. They are all energy efficient with no emissions whatsoever and the cost of maintenance is very low.

A negative impact is that much of the electricity generated today is from fossil fuels, thereby leaving a bad carbon footprint. Also, the charging time to refuel the vehicle when compared to other vehicles is not as attractive, especially when compared the shorter range of the vehicle.

2.5 Biodiesel

Biodiesel is an alternative fuel produced from vegetable oils, animal fats or recycled restaurant grease. Biodiesel and conventional diesel vehicles are one and the same. Biodiesel is most often used as a blend with petroleum diesel fuel, and can be used in many vehicles without any engine modification. The most common biodiesel blend is B20, which ranges from 6 – 20% **Invalid source specified.**.

Biodiesel raises the cetane of the fuel and improves lubricity. A higher cetane number means the engine is easier to start and reduces ignition delay. Diesel engines depend on the lubricity of the fuel to prevent moving parts from wearing prematurely. Improved lubricity reduces friction within the moving parts, avoiding additional wear.

Biodiesel reduces emissions, it is safer than petroleum diesel because it is less combustible and it is biodegradable. It is also safe to handle, store and transport.

Biodiesel performance in cold weather depends on its blend. In general, blends with smaller percentages of biodiesel perform better in cold temperatures. There is also limited production (12).

3. METHODOLOGY

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method is a multi-criteria decision making (MCDM) procedure for ranking different options, in this case fuel alternatives. TOPSIS was selected over other MCDM methods such as Simple Additive Weighing (SAW), because according to Abdullah & Adawiyah (13), the later does not consider the different preferential levels and preferential ranks for each decision maker's assessment of alternatives in a decision group. Therefore, a procedure such as TOPSIS helps in accommodating trade-offs between criteria, thereby overcoming such handicap.

Initially developed by Hwang & Yoon (14) and later modified by Yoon & Hwang (15), TOPSIS combines both subjection input in the rating of criteria weights and objective data to derive the ranking of alternatives.

The first step in applying TOPSIS is the creation of an evaluation matrix consisting of 'm' alternatives and 'n' criteria. This is accompanied by the calculation of the normalized decision matrix using equation (1).

$$\bar{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum X^2{}_{ij}}} \quad (1)$$

Where X_{ij} is the value of i-alternative with respect to j-criterion.

This is followed by the calculation of the weighted normalized decision matrix, which is done by multiplying each cell in the normalized decision matrix by its corresponding weight. After this the ideal best $A^+$and worst A^- solutions are selected. In this step, the positive (+ve) and negative (-ve) criteria are taken into consideration. For +ve criteria, the highest value is more desirable, so it is the ideal best and the lowest value is the ideal worst. For –ve criteria, the lowest value is more desirable so it is the ideal best and vice versa.

Next is the calculation of the Euclidean Distances S^+ and S^- from the ideal best and worst solutions using equation (2).

$$S^+ = \sqrt{\sum (X_{ij} - A^+)^2} \quad \text{and } S^- = \sqrt{\sum (X_{ij} - A^-)^2} \quad (2)$$

The final step involves the calculation of the performance score P from which the alternatives are ranked from highest to lowest. The performance score is calculated with equation (3).

$$P = \frac{S^-}{S^+ + S^-} \quad (3)$$

A team of experts drawn from both the academia and industry participated in the assignment of weights to the different selected criteria/attributes in order to estimate their relative importance Figure 1. Each criterion was assigned points in such a manner that they summed up to 1. Therefore, a rating scale of 0 to 1 was applied. The criteria were further subdivided into six factors.

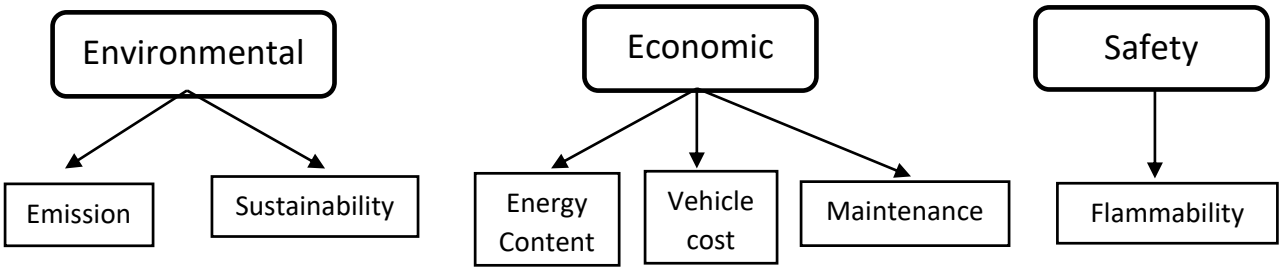

Figure 1: Criteria and factors applied for the evaluation of alternative fuel types

The six factors chosen were compared among the selected alternative fuel using particular vehicles (Table 1). The factors consisted of both qualitative and quantitative inputs, thus making it necessary to apply a MCDM tool for the analysis.

Table 1: Selection of factors with respect to for alternative fuel using particular vehicle types

Fuel Type (Vehicle Type)	Fuel Sustainability	Emissions	Vehicle Cost ($)	Energy Content (MJ/kg)	Maintenance Cost	Flammability (V/v) %
Biodiesel (GMC Terrain 2019 SUV)	Yes	Lower than petrol vehicles	36,000	42.2	Same as Diesel Engine	6.5
Hydrogen (Toyota Mirai 2019)	No	Water	58,500	120.7	Relatively low due to less moving parts	69.9
Electric (Nissan Leaf 2016)	No	No emissions	24,000	-	Relatively low due to less moving parts	-
Compressed Natural Gas (CNG) (Audi A4 2018)	No	Lower than petrol vehicles	37,000	53.6	Relatively low due to cleaner engines	9.7
Ethanol C2H5OH (Chevrolet Impala 2019)	Yes	Lower than petrol vehicles	37,000	29.7	Same as Petrol Cars	14.7

4. Results and Discussion

The ranking of alternative fuel for vehicles was done by means of six factors derived from environmental, economic and safety criteria. Three of the factors; sustainability, tailpipe emission and maintenance cost were first converted from qualitative to quantitative data before further analysis was carried out. Sustainability and maintenance costs ranged from 1 to 2, while tailpipe emission ranged from 1 to 3 (Table 2).

Table 2: Variables used in the evaluation matrix

	Fuel Sustainability	Tailpipe Emission	Vehicle Cost ($)	Energy Content (MJ/kg)	Maintenance Cost	Flammability (%)
Biodiesel	2	2	36,000	42.2	1	6.5
Hydrogen	1	3	58,500	120.7	2	69.9
Electric	1	3	24,000	0.3	2	1
CNG	1	2	37,000	53.6	2	9.7
Ethanol	2	2	37,000	29.7	1	14.7
∑X2	11	30	8,032,250,000	20,104.47	14	5,239.44
$\sqrt{\sum X^2}$	3.3166	5.4772	89622.8207	141.7902	3.7417	72.3840

The variables were then normalized to obtain the same scale for all the factors as shown in Tables 3.

Table 3: Normalized Decision Matrix

	Sustainability	Tailpipe Emission	Vehicle Cost ($)	Energy Content (MJ/kg)	Maintenance Cost	Flammability (%)
Biodiesel	0.6030	0.3652	0.4017	0.2976	0.2673	0.0898
Hydrogen	0.3015	0.5477	0.6527	0.8512	0.5345	0.9657
Electric	0.3015	0.5477	0.2678	0.0021	0.5345	0.0138
CNG	0.3015	0.3652	0.4128	0.3780	0.5345	0.1340
Ethanol	0.6030	0.3652	0.4128	0.2095	0.2673	0.2031

This was followed calculating the weighted normalized decision matrix (Table 4). The weighted normalized decision matrix was derived using the weights assigned by experts, such that Economic criteria was rated highest with 0.43 and Safety had the least score of 0.27. The values were further distributed among the factors.

Table 4: Weighted Normalized Decision Matrix

Weightings	Environmental – 0.3		Economic - 0.43			Safety – 0.27
	0.15	0.15	0.1433	0.1433	0.1433	0.27

	Sustainability	Tailpipe Emission	Vehicle Cost ($)	Energy Content (MJ/kg)	Maintenance Cost	Flammability (%)
Biodiesel	0.0905	0.0548	0.0576	0.0426	0.0383	0.0242
Hydrogen	0.0452	0.0822	0.0935	0.1220	0.0766	0.2607
Electric	0.0452	0.0822	0.0384	0.0003	0.0766	0.0037
CNG	0.0452	0.0548	0.0592	0.0542	0.0766	0.0362
Ethanol	0.0905	0.0548	0.0592	0.0300	0.0383	0.0548

Then the ideal/best solution (A+) and negative ideal/worst (A-) solution were selected. Here we take into consideration the +ve and –ve criteria. For +ve criteria, the highest value is more desirable, so it is the ideal best and the lowest value is the ideal worst. For –ve criteria, the lowest value is more desirable so it is the ideal best and vice versa (Table 5).

Table 5: Weighted Normalized Decision Matrix with Ideal Best and Worst Solutions

	+ve Sustainability	+ve Tailpipe Emission	-ve Vehicle Cost ($)	+ve Energy Content (MJ/kg)	-ve Maintenance Cost	-ve Flammability (%)
Biodiesel	0.0905	0.0548	0.0576	0.0426	0.0383	0.0242
Hydrogen	0.0452	0.0822	0.0935	0.1220	0.0766	0.2607
Electric	0.0452	0.0822	0.0384	0.0003	0.0766	0.0037
CNG	0.0452	0.0548	0.0592	0.0542	0.0766	0.0362
Ethanol	0.0905	0.0548	0.0592	0.0300	0.0383	0.0548
Ideal Best (A+)	0.0905	0.0822	0.0384	0.1220	0.0383	0.0037
Ideal Worst(A-)	0.0452	0.0548	0.0935	0.0003	0.0766	0.2607

The relative closeness to the ideal solution i.e. the performance score (P) was the calculated and this was used to rank the alternative fuel types (Table 6).

Table 6: Euclidean Distances, Performance Score and Ranking of Alternative Fuel Types

	S^+	S^-	$S^+ + S^-$	P	Rank (R)

Biodiesel	0.0886	0.2501	0.3387	0.7384	1
Hydrogen	0.2695	0.1247	0.3163	0.3163	5
Electric	0.1354	0.2643	0.3997	0.6612	4
CNG	0.1018	0.2334	0.3352	0.6963	2
Ethanol	0.1107	0.2190	0.3297	0.6642	3

The rank is obtained from the performance score with the highest value as the most favorable alternative. From the scores calculated, the fuels in order of suitability in the Nigerian economy are; biodiesel, compressed natural gas, ethanol, electricity and hydrogen.

Biodiesel, compressed natural gas and ethanol will be more easily be incorporated in Nigeria than electricity and hydrogen due to their low cost of vehicle and fuel, fuel availability, low cost of maintenance and low emissions. Electricity and hydrogen although not yet ready for our environment due to the lack of supporting infrastructure and high cost of vehicle are also very good options of alternative fuels.

4.2 Sensitivity Analysis

To analyze the robustness of the results obtained from experts, a sensitivity analysis was carried out. Here, the weighted score of 0.3333 is used for each of the factors; environmental, economic and safety. It is then subdivided for environmental and economic factors to get their individual weights. Then the weighted normalized matrix, ideal best and worst values are calculated as shown in Table 7.

Table 7: Weighted Normalized Decision Matrix with Ideal Best and Worst Solutions

	+ve	+ve	-ve	+ve	-ve	-ve
Weightings	Environmental -0.3333		Economic – 0.3333			Safety-0.3333
	0.1500	0.1500	0.1111	0.1111	0.1111	0.3333
	Sustainability	Tailpipe Emission	Vehicle Cost ($)	Energy Content (MJ/kg)	Maintenance Cost	Flammability (%)
Biodiesel	0.1005	0.0609	0.0446	0.0331	0.0297	0.0299
Hydrogen	0.0503	0.0913	0.0725	0.0946	0.0594	0.3219
Electric	0.0503	0.0913	0.0298	0.0002	0.0594	0.0046
CNG	0.0503	0.0609	0.0459	0.0420	0.0594	0.0447
Ethanol	0.1005	0.0609	0.0459	0.0233	0.0297	0.0677
Ideal Best (A+)	0.1005	0.0913	0.0298	0.0946	0.0297	0.0046
Ideal Worst(A-)	0.0503	0.0609	0.0725	0.0002	0.0594	0.3219

The Euclidean Distances from the ideal best and worst values i.e. (S+ and S-) were calculated for the equal weights as displayed in Table 8.

Table 8: Euclidean Distances from Ideal Best and Worst Solutions

	Sustainability	Tailpipe Emission	Vehicle Cost ($)	Energy Content (MJ/kg)	Maintenance Cost	Flammability (%)	S^+	S^-
Biodiesel	0.1005	0.0609	0.0446	0.0331	0.0297	0.0299	0.0746	0.3009
Hydrogen	0.0503	0.0913	0.0725	0.0946	0.0594	0.3219	0.3254	0.0992
Electric	0.0503	0.0913	0.0298	0.0002	0.0594	0.0046	0.1110	0.3216
CNG	0.0503	0.0609	0.0459	0.0420	0.0594	0.0447	0.0947	0.2816
Ethanol	0.1005	0.0609	0.0459	0.0233	0.0297	0.0677	0.1012	0.2631
A+	0.1005	0.0913	0.0298	0.0946	0.0297	0.0046		
A-	0.0503	0.0609	0.0725	0.0002	0.0594	0.3219		

Finally, the performance score was calculated and the alternative fuels are ranked as shown in Table 9.

Table 9: Euclidean Distances, Performance Score and Ranking using Equal Weights

	S^+	S^-	$S^+ + S^-$	P	Rank (R)
Biodiesel	0.0746	0.3009	0.3755	0.8013	1
Hydrogen	0.3254	0.0992	0.4246	0.2336	5
Electric	0.1110	0.3216	0.4326	0.7434	3
CNG	0.0947	0.2816	0.3763	0.7483	2
Ethanol	0.1012	0.2631	0.3643	0.7222	4

The sensitivity analysis indicates that, there is no variation in the ranking of Biodiesel and CNG as the first and second choices. The same cannot be said about the three alternative fuel types as their positions were altered.

5. CONCLUSION

In this study, the focus was on the review and evaluation of five different alternative fuel types; Biodiesel, Ethanol, Electricity, Hydrogen and Natural Gas, to ascertain which would be better utilized for vehicular transportation in Nigeria. The review exposed the pros and cons of the alternative fuels. The evaluation was based on three criteria; Economy, Environment and Safety and six factors; Sustainability, Tailpipe Emissions, Vehicle Cost, Energy Content, Maintenance Cost and Flammability Volume. The Multi-Criteria Decision Making (MCDM) tool employed in this study was the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), which ranked and selected a number of possible alternatives by measuring Euclidean distances. Biodiesel was ranked the highest, followed by Compressed Natural Gas, Ethanol, Electricity and Hydrogen. Biodiesel fared better than the rest due to its sustainable nature, less emission, high energy content and also already available infrastructure. Hydrogen and

Electricity ranked lowest due to their high cost of infrastructure and vehicle cost. The utilization of alternative fuels in Nigeria would not only go a long way in reducing harmful emissions but will also help in increasing energy efficiency.

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