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A COMPARATIVE AND ENERGY ANALYSIS ON THE USE OF GAS FUEL SOURCES FOR THE TRANSPORT SECTOR IN NIGERIA

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Abstract

Transportation-related energy use comprises the energy used to move people and products by pipeline, pipeline, rail, air, and water. The growth rates of the economy and the population of people who can drive will determine how much energy is needed by the transportation industry. Increased industrial output is a result of economic expansion, which calls for the transportation of raw materials to manufacturing facilities as well as finished items to consumers. The number of liquid fuels used for transportation in Nigeria grew between 2005 and 2009. Fuels used in light-duty vehicles, buses, airplanes, and passenger trains are included in the category of passenger transportation energy use. Large trucks, freight trains, as well as local and foreign marine vessels, all need gasoline in the movement of freight. This paper discusses, among other things, the modes of transportation and their patterns of energy consumption while examining the effects of this trend on the country's energy consumption. It also provides some insightful information on the necessity of gaseous fuels in Nigeria as a strategy to achieve fuel diversification within the context of the Nigerian economy. This study assesses several gas fuels using the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), a Multi-Criteria Decision Making (MCDM) tool while taking into account the financial, environmental, *and safety aspects of each gas fuel source. For the research to produce a well-rounded point of view, numerous academic research articles have to be consulted. Based on the results, LPG was ranked top, followed by CNG, LNG, butane, and hydrogen. The different gas fuel sources were also prioritized in order of importance in Nigeria. Due to its extreme flammability and high fuel expense per GGE, hydrogen came in last.*

Keywords: Gas fuel sources, Energy consumption, Transportation modes, Liquefied Petroleum Gas, Liquefied Natural Gas, Compressed Natural Gas

INTRODUCTION

Urbanization has resulted in an increase in energy consumption, and global population growth and quickening transportation development have both boosted the need for energy globally. The transportation industry is the largest consumer of oil in the world, using up 60% of all oil produced. As a result, it is also the largest emitter of greenhouse gases, contributing around 20% of all CO_2 emissions (IEA, 2014). Transportation-related energy use comprises the energy used to move people and products by pipeline, rail, air, and water. Light-duty vehicles, such as cars, sport utility vehicles, minivans, small trucks, tricycles, and motorcycles, as well as heavy-duty vehicles, such as big trucks used for hauling freight and buses used for passenger transportation, are all included in the road transport component. As a result, growth rates for the economy and the population of people who can drive will determine how much energy is needed by the transportation industry. Increased industrial output is a result of economic expansion, which calls for the transportation of raw materials to manufacturing facilities as well as finished items to consumers. The nation's energy consumption is significantly influenced by the transportation industry, notably in Nigeria, which also has a significant impact on the nation's energy balance (Chukwu et al., 2015).

There is rising concern that the world's supply of fuels based on petroleum may run out. The rising demand for carbon emissions and climate change from conventional fuel sources (Achtnicht, et al., 2012) has led to the consideration of alternate sources, such as liquefied natural gas and compressed natural gas as fuel (Okon, 2018). Driving cars that use compressed natural gas or liquefied natural gas will again result in a major reduction in the roughness and difficulties that are related to fuel importation into the country. Natural gas, a hydrocarbon gas and a source of fossil fuel-based energy, is a mixture of methane, carbon dioxide, and nitrogen (Maijama et al., 2020).

After ethanol, Autogas is the second most popular and widely recognized alternative vehicle fuel in use today. Autogas is composed of compressed natural gas and liquefied petroleum gas used as a transport fuel. The amount of auto-gas consumed globally has been increasing quickly in recent years. In 2016, there were 26.7 million tons consumed, up 3.7 Mt (16% from 2000) and 283 000 tons (1.1%) from 2015. Nearly 26.8 million auto-gas vehicles are currently in operation worldwide (Morgan, 2017). The need for eco-friendlier, better, and cleaner fuels has been driven by the problems posed by global warming. The most popular and expensive types of petroleum fuels are Premium Motor Spirit (PMS) and Automotive Gas Oil (AGO) (Adewale et al., 2020).

The environment is the main justification for why governments in many nations actively promote the use of autogas and other alternative fuels. In most studies evaluating environmental performance that have been done globally, auto-gas surpasses gasoline and, especially, diesel, as well as certain other alternative fuels. In terms of harmful pollutants, auto-gas emissions are particularly low. When emissions are measured over the course of the whole fuel cycle and the LPG is mostly derived from natural gas processing plants, autogas outperforms both gasoline and diesel in terms of greenhouse gas emissions (Morgan, 2017).

Natural gas is frequently produced from underground coal beds or fields of crude oil, and it is frequently utilized to generate energy and heat homes. For instance, because natural gas is lighter than air, its compressed form can store pressures of approximately 20–32 MPa (Hai, 1993). The brawny tank is a storage tank that takes up extra room in the car. Natural gas is safer than gasoline and diesel since it is lighter and easier to release, and more importantly, vehicles that use compressed natural gas are typically used for light-duty vehicles (Zhang, 2015). However, in terms of energy density, liquefied natural gas has double the capacity of compressed natural gas, which is supplied in specially built tanks with cool temperatures of around 165 and lower pressures of roughly 70–150 psi. It is typically used by heavy-duty vehicles, and because liquefied natural gas has a higher energy density, refueling is comparatively less expensive because it uses 100 times less electric power than compressed natural gas. Natural gas use has a several advantages, including improved air quality, increased energy security, lower operating costs, and reduced noise in the community. As a result, it is widely acknowledged to be the best substitute for gasoline and diesel in cars. Although natural gas is a non-renewable energy source, a number of methods have been developed that can produce bio-natural gas, including bio-methane, biogas, and biosynthetic gas (Michiel, 2010).

Additionally, the per-litre pump price of gasoline may have an impact on the price of natural gas. The price of natural gas at the pump per litre has historically been more steady than the price of gasoline, and in more recent years, the price of natural gas at the pump per litre has decreased relative to the price of gasoline, allowing for a decrease in operating costs (Michiel, 2010). Zhang (2015) offered evidence in support of this claim, claiming that the cost of using natural gas is 20–60% lower than that of gasoline and 20–40% lower than that of diesel. Again, the retail pump price of natural gas per litre is typically lower than the adjustable price of gasoline in many nations.

Despite all of these factors, Nigeria is currently exporting 18.6 million tons of liquefied natural gas annually (IGU, 2017), while the population is using more liquefied petroleum gas at home. Improving these figures and increasing the use of additional natural gas fractions have numerous benefits. Additionally, in Nigeria, the automotive industry is frequently more affected by PMS retailing instability, which has continued to be a source of disputes between the government and the labour union (Ubani and Ikpaisong, 2018). If alternatives like compressed natural gas (CNG) and liquefied natural gas were developed, this issue may be solved. Since LPG would lower fuel prices for the general people, reduce CO_2 emissions, and, most significantly, do away with the need for premium motor spirits subsidies, we are attempting to shine more light on the advantages of LPG to the Nigerian car sector (Maijama et al., 2020).

The success of actual legislation and measures, however, may not always accurately represent the genuine environmental advantages of transitioning from conventional car fuels to auto gas. The best policies for encouraging the use of auto gas are those that assist the fuel become more competitive with gasoline and diesel while providing a significant financial incentive for end users to do so. In reality, the cost of converting an existing gasoline vehicle (or the additional cost of purchasing a factory-built auto gas vehicle compared to an equivalent gasoline or diesel vehicle) and the pump price of auto gas relative to diesel and gasoline determine how financially attractive auto gas is compared to other fuels. In other words, decreased maintenance costs, of which fuel is the most crucial, should make up for the higher initial cost for the car owner. The usage of the vehicle, or the average distance travelled monthly or yearly, determines the time it takes for the running cost savings to equal the capital cost, or the payback period. For commercial vehicle owners to switch, the payback period typically needs to be less than two to three years; private customers frequently seek a speedier return on their investment (Adewale et al., 2020).

The purpose of this study is to examine the energy consumption patterns in the transportation sector of Nigeria and explore the potential use of gaseous fuels as a strategy for fuel diversification within the country's economy. Using academic research articles and evaluating the different gas fuels, the study seeks to determine their ranking and prioritize their importance in Nigeria. Ultimately, the study aims to provide insights into the potential benefits and implications of adopting gaseous fuels in the transportation sector of Nigeria.

LITERATURE REVIEW

Recent years have seen a need to move beyond liquid fuels (gasoline, diesel) as vehicle fuels due to the nation's limited crude oil reserves and calls for the deregulation of the petroleum sector of the economy. Natural gas as a motor fuel has been proposed as a viable option. Natural gas has advantages over liquid fuel for automobiles, such as a higher octane rating, fewer adverse effects on engine components, and lower effluent toxicity. Along with the efforts made by Nigeria through the Nigerian Gas Company (NGC) Limited to experiment with the project, experiences of other nations that currently use natural gas as an automobile fuel are reviewed. It is also stressed the importance of government participation through the NGC in the creation and implementation of a refit plan to enhance the pipeline network and provide natural gas to refueling and refilling stations (Oghenejoboh & Akpabio, 2002). On the other side, the general population needs to be educated about the necessity of converting their cars to gas or gasoline-powered ones and provide incentives for using natural gas filling stations. Effective distribution and consumption of natural gas within the Nigerian socioeconomic sector will be facilitated by a cogent interaction of both national and corporate interests in policy design and implementation (Oghenejoboh & Akpabio, 2002).

The dimethyl ether, Fischer-Tropsch, vegetable oil, and bio-diesel oil are the four substitute fuels listed by Demirbas (2006) as being suitable for use in conventional CI engines. Because both of these fuels can be produced from natural gas, they are not constrained by the availability of feedstock. However, diesel engines have some advantages over Otto cycle engines in terms of efficiency level, and the main constituents of gasoline are aromatics, including olefins, naphtha, and paraffins. As a result, the principal fuel substitutes are liquefied petroleum gas, alcohol, compressed natural gas, and petrol-powered electric vehicles.

According to Adom et al. (2012)'s study for the conditional requirement of electricity consumption in Ghana, per capital real income, industry efficiency, changes in the economy's structure, and the degree of urbanization is regarded as the key determinants of demand for electricity in the case of the Ghanaian economy. However, there are few empirical studies on the demand for natural gas, and more specifically LPG.

According to Chikezie and Udoka (2013), the world's need for energy will continue to soar as economies around the world advance. Due to its affordability, accessibility, adaptability, and cleanliness, natural gas is anticipated to surpass other fossil fuels in terms of demand. The International Energy Agency (IEA), for instance, predicted in May 2012 that the demand for natural gas worldwide could increase by more than 50% from 2010 levels by 2035. The Intergovernmental Panel on Climate Change (IPCC) states that in order to prevent drastic effects of global warming, global greenhouse gas (GHG) emissions must be cut by 50 to 80 percent by 2050. We must develop all commercially feasible energy sources in order to meet this increasing energy demand and reduce GHG emissions. Since the world's energy needs are increasing, we are aware that no one energy source can supply them. Additionally, we require a more varied energy mix to ensure energy security and combat climate change. We must develop all affordable and environmentally responsible energy sources in order to meet this long-term societal demand. There is natural gas accessible to provide the world a practical substitute because it is the cleanest fossil fuel. Its availability, consistency, adaptability, and abundance will be crucial.

According to Kafood (2014), natural gas has continued to be seen as the most promising alternative to other fossil fuels because of its purity and richness. Natural gas has recently acquired popularity across a variety of industries, including the transportation sector where it has supplanted diesel, petrol, and other fuels. Some percentage of cars run on CNG today, and their number is expanding everyday, primarily due to its moderately lower costs and the growing awareness of operators on air pollution. In the example of the Ghanaian economy, Mensah (2014) analyzed the long- and short-term drivers of LPG demand and exposed 10 years of future trends projections with the use of ARDL and partial adjustment model techniques. Their findings showed that price, income, and urbanization are the main demand determinants, while predictions from all three scenarios indicate that LPG demand will reach a minimum amount of 5.9 million metric tons in the year 2022, implying that there will be a shortage of LPG.

In Nigeria, gasoline and automotive gas oil are the two types of petroleum fuel that are utilized in cars. The number of cars is predicted to be 11.7 million (National Bureau of Statistics, 2018), and their carbon emissions are very significant. These fuels also have high production costs and fuel pump prices. The usage of these fuels cannot be sustained in the long run, either for the economy or the environment. There is no robust national fiscal policy that guarantees cost-reflective investments for vehicle gas, and there is no fiscal policy that accounts for the switching cost of gas fuels as they relate to the downstream domestic market in Nigeria. When an economy is dependent on the importation of petroleum products and the population is growing at a rate that is almost three times faster than the GDP, using gasoline and automotive gas oil as standard transportation fuels is not sustainable (Adewale et al., 2020). Nigeria's debt increased to roughly 11 trillion naira as of 2015 due to financial obligations from PMS under-recovery (NBS, 2016).

Ogunlowo (2016) observed that quite a number of things have prevented Nigeria from using compressed natural gas as a transportation fuel, including a lack of focus, an unfavorable energy market structure, a lack of access to capital, an insufficient public awareness campaign, a lack of organizations to enforce vehicle standards, and the weak structure of the transport market based on the participant's perceptions from the case study.

In order to reduce CO_2 emissions, Otene et al. (2016) highlighted the capability of converting flared gas from the Nigerian oil and gas industry into compressed natural gas, which may be the best option for the 220 Lagos Bus Rapid Transit. Additionally, the BRT-energy Lite's usage and CO_2 emissions were modeled using current circumstances and projections for the year 2030 using the LEAP software. The Lagos BRT-Lite will use compressed natural gas, according to the model's outcome, which will lower CO_2 emissions in the nation's oil and gas sector. The industry's additional gas consumption options include liquefied petroleum gas, liquefied natural gas, and power generation.

Ubani and Ikpaisong (2018) argued that natural gas is a clean-burning, secure fuel that can lower your fuel costs, improve the environment, and lessen Nigeria's reliance on oil. It is a naturally occurring combination of gaseous hydrocarbon, non-gaseous non-hydrocarbons, and gaseous non-hydrocarbons that can be found either on its own (non-associated gas) or in conjunction with crude oil in subsurface reservoir rocks (associated gas). Because it is more environmentally friendly than other types of fossil fuels, natural gas is now recognized as one of the finest energy sources for the present and the future. Nigeria, which sits atop around 128 trillion cubic feet of natural gas resources, is listed as the seventh-most natural gas-rich country in the world and currently holds the top ranking in Africa. Nigeria now has the ability to use LNG (liquefied natural gas), LPG (liquefied petroleum gas), CNG (compressed natural gas), gas to reinjection schemes, gas to power schemes, gas to petrochemicals (as feedstock), and LNG (liquefied petroleum gas). With an emphasis on the financial advantage, compressed natural gas (CNG) use as motor fuel in Nigeria offers a wide range of advantages. Natural gas is compressed to a tenth of the volume it would have at regular atmospheric pressure to create compressed natural gas (Adewale et al., 2020).

In their evaluation of liquefied petroleum gas as a substitute fuel, Synáka et al. (2019) demonstrated that liquefied petroleum gas is a mixture of butane, propane, and other smaller-volume substances that is produced as a by-product of petroleum refining. The authors evaluated liquefied petroleum gas from the perspectives of economics, safety, and emissions. As part of their research into using gas as a vehicle fuel in Nigeria.

Adegoriola and Suleiman (2020) demonstrated that using gas as fuel has some advantages in terms of efficiency and the environmental impact, driving its demand to surpass that of other fossil fuels currently in use. Although its adoption in the short term comes with some challenges, in the long run it seems to be the best option because it is affordable and, most importantly, clean in terms of greenhouse gas emissions.

In their study on the environmental impact of crude oil price and urbanization using the ARDL method for the 1981–2016 period, Maijama and Musa (2020) found that there is a strong co-integration relationship among the series and that crude oil price and foreign direct investment have a positive and significant sign with environmental pollution in the long run, suggesting that income from crude oil exports and foreign capital inflows help in maintaining the quality of the environment. However, urbanization had favourable and significant long-term and short-term trends, indicating that it was a major contributor to environmental pollution.

METHODOLOGY

A qualitative approach was first applied to analyze the oil and gas energy utilization data, sourced from secondary materials; International Energy Association, Nigerian National Petroleum Cooperation (NNPC) Annual Statistical Bulletin, Journals, etc. This analysis was followed by an optimization approach that uses a Multiple-Criteria Decision Making (MCDM) tool called Technique for Order of Preference by Similarity (TOPSIS). This tool was used to perform a comparative analysis between automotive gas fuels. An Excel statistical tool was used for analyzing evaluating, and graphically representing the data. An optimization model using python was further integrated to compare and evaluate the best gas fuels based on relevant features.

Nigeria Energy consumption by Sources

This describes the Total Final Consumption (TFC) by end users, such as industry, agriculture, households, etc. Based on our analysis, biofuels and waste contribute to the highest share of total energy consumption in Nigeria. This is followed by oil products, natural gas, and coal respectively. About 157234.0TJ of total natural gas energy was consumed at the end of 2019. This accounts for 3.456% of biofuels and waste, and 18.13% of oil products comparing the TFC. This implies that natural gas has not been optimally utilized by the end users when compared with Biofuels, waste, and oil products.

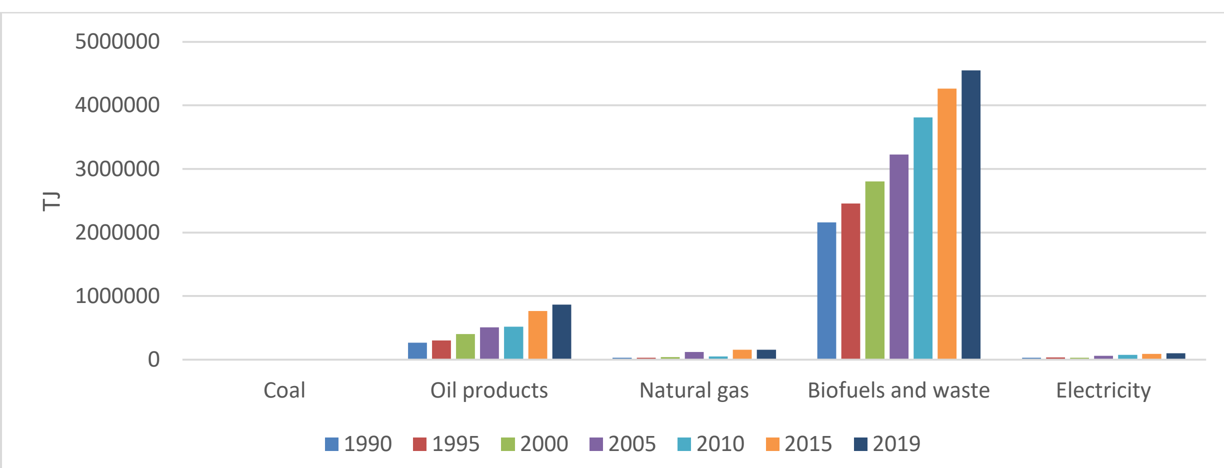

Figure 1: Total Energy consumption by Sources(IEA, 2019)

Gas Utilization in Nigeria

In Nigeria, a total of 81 wells were drilled, including 5 exploratory wells and 76 development wells. In the gas sector, a total of 2729.1 Billion cubic feet of Natural Gas was produced in 2020 (NNPC, 2020). The amount of gas produced declined by 4.74% when compared to the previous year (2019), because of the spread of the COVID-19 pandemic which led to the lockdown of several operatives that function in the exploration and production of gas wells. Out of the gas produced, 92.92 was reutilized and 7.08 was flared (NNPC, 2019).

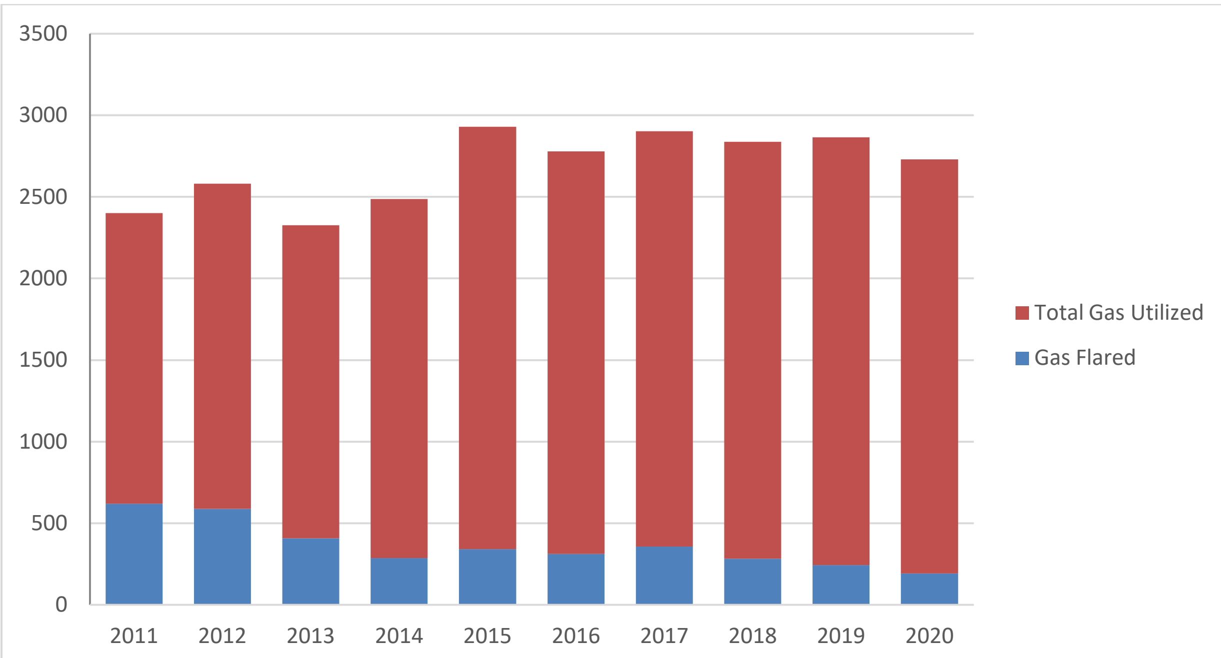

Figure 2: Gas flared vs Gas Utilized (NNPC, 2022)

From the above plot, we observe that as the amount of gas flared depreciated, the volume of gas utilization increased over the last 10 years. This is a positive sign in the advancement of gas consumption in various sectors and the curtailing the Green House Gas emission. Moreover, according to National Oil Spill Detection and Response Agency (NOSDRA), Nigeria has lost a total of 891 billion Naira to gas flaring from 2021 to 2022 and flared a total of 126bscf in the first half of 2022. This estimation for the first half of 2022 is equivalent to an increase of 4.46 percent in carbon emission when compared to the 120.5bscf gas flared in 2021. The quantity of gas flared if properly utilized can be converted to a useful energy source of automotive fuel in form of Green Hydrogen, Compressed Natural Gas (CNG), and Liquefied Petroleum Gas (LPG) for Natural Gas Vehicles (NGVs).

Nigeria has abundant proven reserves of crude oil, condensate, LNG, and other petroleum products. Natural Gas, liquefied or compressed (LNG, CNG) is the major component of non-blended alternative fuels. The end use of energy consumption in Nigeria is more dominant in the residential sector than the transport sector. This is because the use of LPG is used predominantly as cooking gas while its full potential as an alternate gas fuel has not been fully utilized. LPG domestic product yield reduces from 1276871Mt to 52154 Mt, while other fossil fuels (AGO, PMS, and DPK) following the same trend have a higher yield than LNG.as we move from the year 2011 to 2018.

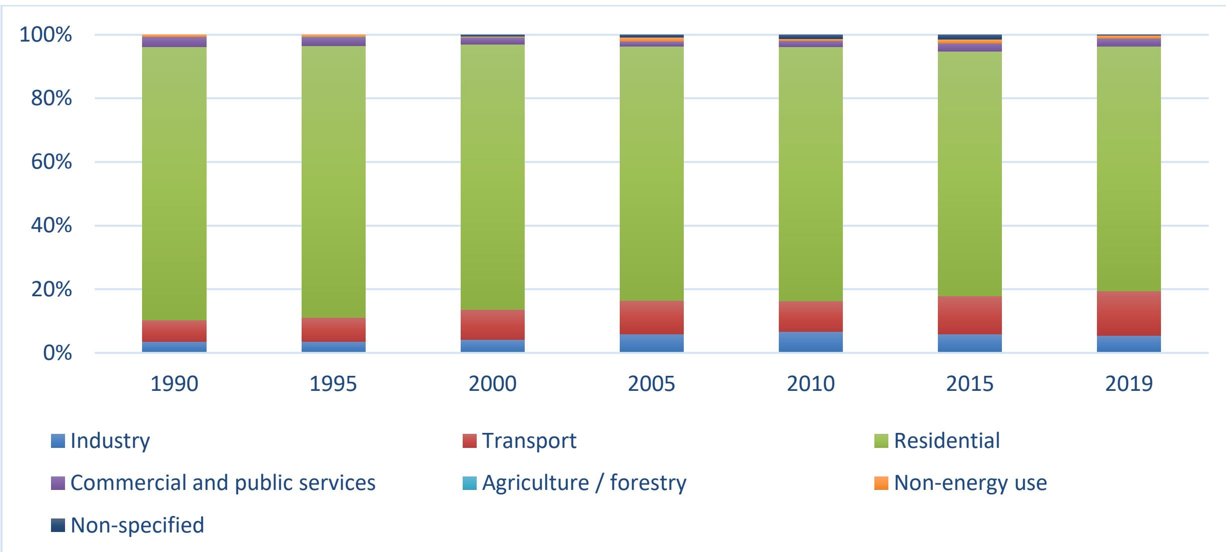

Figure 3: Energy consumption by sector (IEA, 2019)

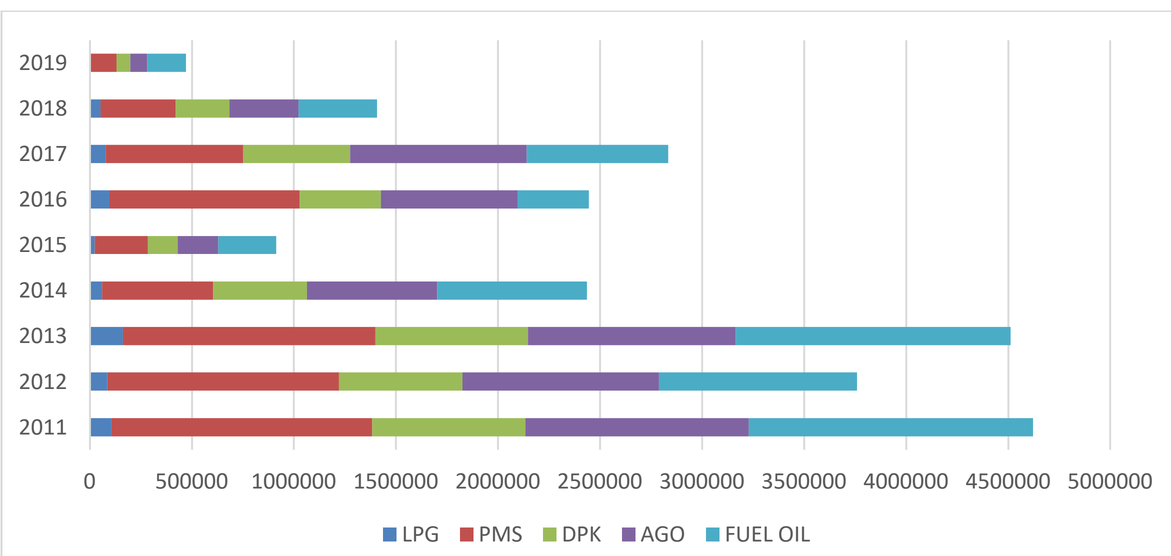

Figure 4: 10-year Domestic product yield (NNPC, 2019)

Greenhouse Gas Emission (GHG) In Nigeria

The Energy trend in Nigeria is determined by the regulation of GHG. The anthropogenic carbon dioxide (CO_2) emission comes majorly from the combustion of fossil fuels; coal, petroleum, and natural gas. Major contributions come from Electrical power plants, industries (manufacturing and production), resident, deforestation, etc. CO_2 is the most important greenhouse gas among others. Measuring the metric tonnes of CO_2 is a relevant indicator in improving the sustainability index of the economy. In Nigeria, the amount of CO_2 emitted into the environment increases yearly and peaks in 2019 as seen in figure 5. The highest driver of Carbon emission is seen in the transport sector, emitting a total of 56 Mt CO_2 as of 2019. The growth rate is determined by the demand for transportation per capita. The increasing population census and the use of energy in Nigeria are major drivers for CO_2 emission.

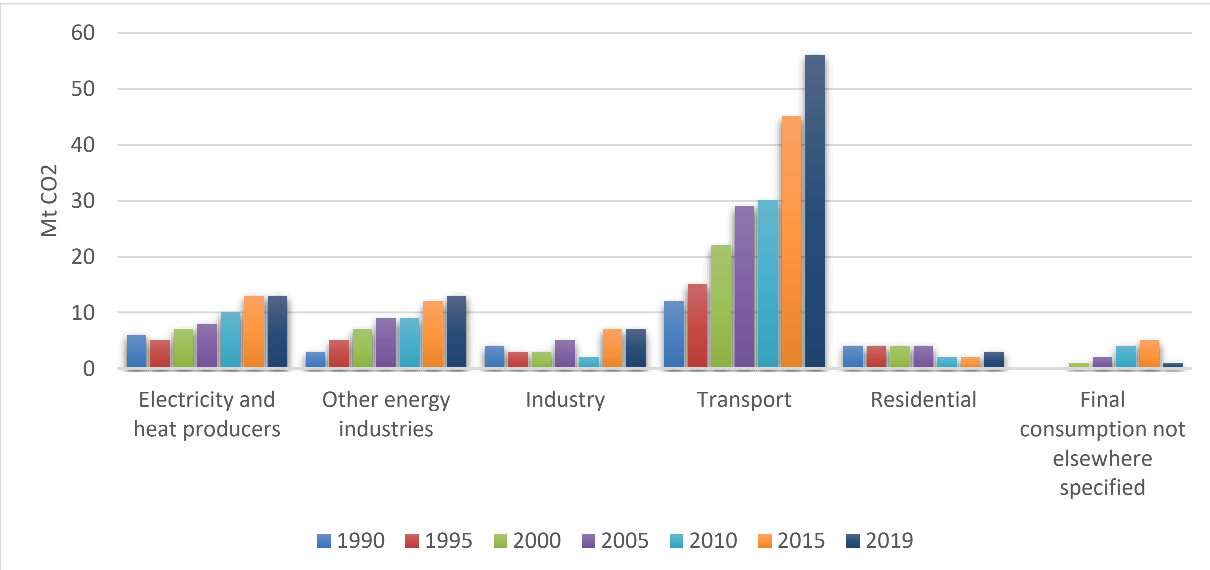

Figure 5: $C0_2$ Emission in Nigeria (IEA, 2019)

For a sustainable economy to thrive, the carbon emission intensity must be brought to path zero. Its raging effect in the transport sector in Nigeria must be curtailed. The transport sector is a major sector in the economy where all classes of citizens are actively engaged in.

The use of fossil fuels in Nigeria is the major contributor to the high greenhouse effect. Although fossil fuels are dominant, easily accessible, cheap, and contain high energy value, they release harmful by-product that pollutes air, and water and causes land degradation. LPG in its automotive state called auto-gas has been adopted by countries - Turkey, Russia, Poland, Ukraine, Korea, etc. Its success in these countries has lowered the emission of noxious gas, thereby enhancing a friendly ecosystem.

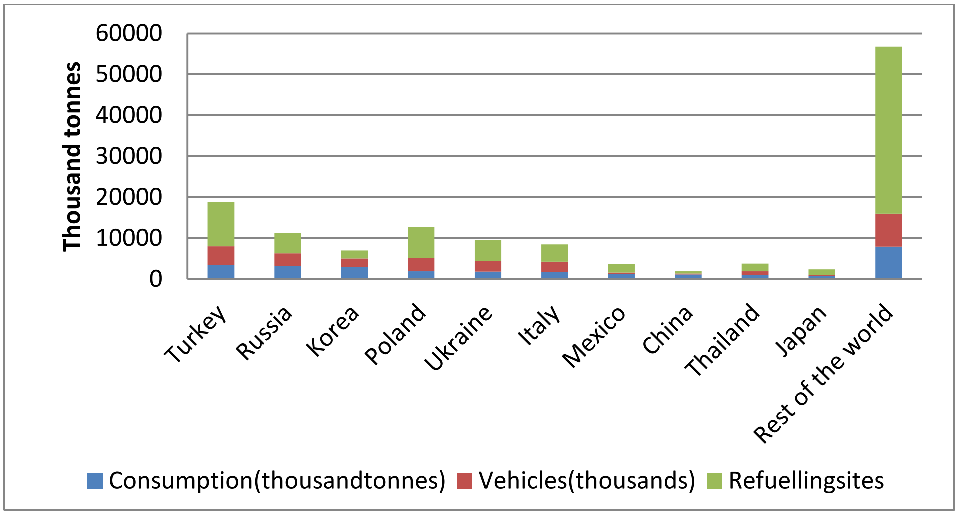

Figure 6: Top 10 countries that use autogas, WLPGA, 2020

Comparative study of gas fuels as automotive alternatives

Using Nigeria economy as the basis of our data computation, the following assumptions were made;

1. One mole of CO_2 produced from one mole of hydrocarbon
2. Fuel cost in USD per Gasoline Gallon Equivalent
3. Weights and criteria for optimization were gotten from experts and research studies

Table 1: Selection factor for gas fuels

Gas Fuel Type	Fuel sustainability	Carbon emission (kg/kg of fuel)	Fuel cost per GGE ($/GGE)	Energy Content (MJ/kg)	Maintenance Cost	Flammability (V/v) %
Hydrogen	Yes	0	5.91	120.7	1	75
CNG	Yes	2.75	2.76	53.6	1	16.4
LNG	Yes	2.75	3.54	47.26	2	10.4
LPG (Propane)	Yes	3	5.19	53	1	10
Butane	Yes	3.03	5.08	54.66	1	8.41

Sources: Engineering Toolbox, (2005); Omo-Irabor, (2020), Alternative Fuel Price Report, (2022)

Table 1 shows six factors that were carefully selected in other to perform a comparative analysis among the gas fuel types. The data consist of both numeric and categorical values thus we can apply Multiple-Criteria Decision Making (MCDM) tool for analyzing the data.

In other to make a decision, we use The Technique for Order of Preference by Similarity (TOPSIS). TOPSIS originated in the 1980s by Hwang and Yoon as a multi-criteria decision-making method that compares the alternatives by providing weights for each criterion through a compensatory aggregation. Therefore, it normalises the scores for each criterion and calculates the geometric distance between each alternative and the ideal alternative. TOPSIS chooses the alternative of the shortest Euclidean distance from the ideal solution, and the greatest distance from the negative-ideal solution (Omo-Irabor, 2020).

The features from the above table were selected with the motive of segmenting the analysis into environmental, economic, and safety considerations. The observations were further used to rank the best gas fuel type. The data are presented as both numerical and categorical data. In other to carry out TOPSIS, all values must be numerical, thus the categorical values are encoded numerically. Fuel sustainability, and emission represent the factors that consider the environmental effect, while fuel cost per Gasoline Gallon Equivalent (GGE), Energy content, and Maintenance cost act as economic indicators, and flammability characterizes safety measures. The categorical values were imputed numerically, ranging from 1 to 2, for easy readability and scalability during analysis.

Table 2: Evaluation Matrix For each Fuel Gas

Gas Fuel Type	Fuel sustainability	Carbon emission (kg/kg of fuel)	Fuel cost per gal ($/GGE)	Energy Content (MJ/kg)	Maintenance Cost	Flammability (V/v) %
Hydrogen	1	0	5.91	120.7	1	75
CNG	1	2.75	2.76	53.6	1	16.4
LNG	1	2.75	3.54	47.26	2	10.4
LPG (Propane)	1	3	5.19	53	1	10
Butane	2	3.03	5.08	54.66	1	8.41

Fundamental principles used in performing the comparative analysis between auto-gas fuels;

Step 1: An evaluation matrix consisting of 5 alternatives and 2 criteria with the intersection of each alternative and criteria. For this case study, the alternatives are gas fuel types and the criteria were either True (prefer higher value) or False (prefer lower value).

Step 2: The evaluation matrix was normalised to form the matrix ($x_{m \times n}$) using the equation given below (TOPSIS, 2022).

$R = (r_{ij})_{m \times n}$ using the normalisation method.

$$r_{ij} = \frac{x_{i,j}}{\sqrt{\sum_{k=1}^{m} x_{jk}^2}} \quad i = 1,2 \ldots m \quad j = 1,2 \ldots . n \quad (1)$$

Step 3: The weighted normalised decision-matrix was calculated.

The weights 0.3, 0.43, 0.27 were used to represent environmental, economic and safety considerations

Where;

$$\frac{W_{i,j}}{\sum_{k=1}^{n} W_{k,j}} \quad (2)$$

Hence,

$$\sum_{i=1}^{n} w_i = 1 \; and \; W_J \; is \; the \; original \; weight$$

Step 4: Determine the worst alternative

$$A_w = \{(\max(t_{ij} | \, i = 1,2, .. m) | \, j \in J_-), (\min(t_{ij} | \, i = 1,2, .., m) | \, j \in J_+)\} \equiv \{t_{wj} | j = 1,2, .., n\}, .. (3)$$

$$A_w = \{(\min(t_{ij} | \, i = 1,2, .. m) | \, j \in J_-), (\max(t_{ij} | \, i = 1,2, .., m) | \, j \in J_+)\} \equiv \{t_{bj} | j = 1,2, .., n\}, \qquad (4)$$

Where,

$$J_+ = \{j = 1,2, .. n | j\} \; asspciated \; with \; criteria \; having \; positive \; impact$$

$$J_- = \{j = 1,2, .. n | j\} \; asspciated \; with \; criteria \; having \; negative \; impact$$

Step 5: Calculate the L2-distance between the target alternative i and the worst condition A_W

$$d_{iw} = \sqrt{\sum_{j=1}^{m} (t_{ij} - t_{wj})^2}, i = 1,2, .. m \quad (5)$$

And distance between alternative i and best condition A_b

$$d_{ib} = \sqrt{\sum_{j=1}^{m} (t_{ij} - t_{bj})^2}, i = 1,2, .. m \quad (6)$$

Where,

d_{iw} and d_{ib} are L^2-norm distances from the target alternative i to the worst and best conditions respectively.

Step 6: Calculate the similarity to the worst condition

$S_{iw} = d_{iw}/(d_{iw} + d_{ib})$, $0 \leq S_{iw} \leq 1$, I =1,2,…,m (7)

$S_{iw} = 1$ only if the alternative solution has the best

$S_{iw} = 0$ only if the alternative solution is the worst condition

Step 7: Rank the alternative according to S_{iw} (I = 1,2,…m)

RESULTS

Using a Source code for TOPSIS optimization algorithm in python, the output generated can be seen in Appendix B. The table below shows the final scores after running the program.

Table 3: Fuel Gas Ranking

Model	Gas Fuel Type	Best Distance	worst distance	Score	Rank
1	Hydrogen	0.233	0.12622546	0.351427	5
2	CNG	0.097	0.219	0.69198	2
3	LNG	0.110	0.231	0.67635	3
4	LPG	0.105	0.235	0.692445	1
5	Butane	0.116	0.235	0.668465	4

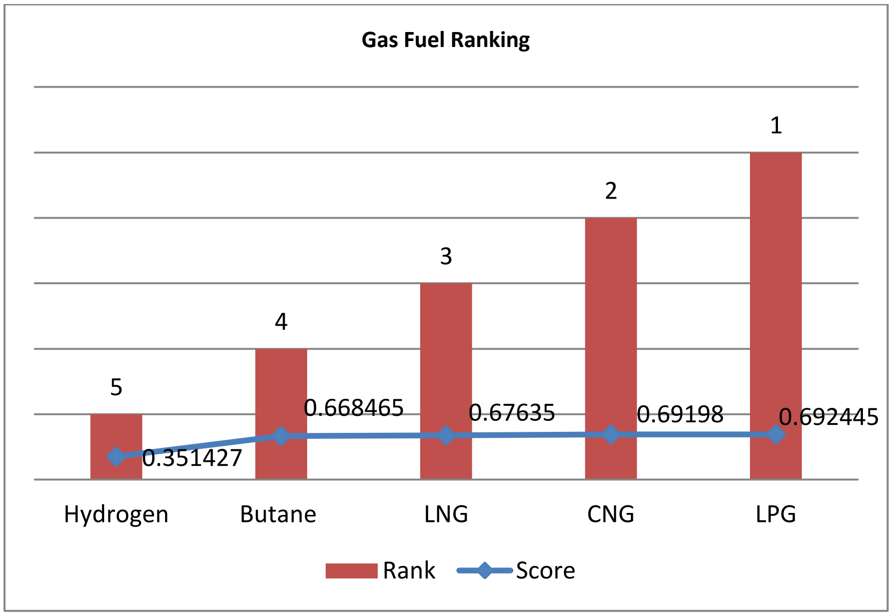

Figure 7: Ranking alternative gas fuel based on performance scores

DISCUSSION

The result in table 3 shows the ranking of gas fuels based on a multiple-criteria approach. The ranking reflects the performance score for each factor, thus enhancing the decision-making process for choosing the best alternative fuel. The gas fuels with the highest rank represent the most suitable alternative that is favorable for Nigeria's economy. From the figure above, we observe a trend rising from Hydrogen, butane, LNG, CNG, and LPG with scores of 0.351, 0.668, 0.677, 0.692, and 0.696 respectively. The variance in the distance between the alternatives and the ideal is seen in the best distance column. LPG which is the highest in rank means it has more potential to meet the energy demand than other fuels. The use of LPG as gas fuel will be highly scalable if it's properly utilized by both the public and private sectors. From the best distance column, the smallest distance was LPG. The smaller the distance, the more ideal the Autogas and vice versa.

Environmental Consideration: The fuel sustainability and emission features accounted for the environmental consideration in table 1. The rationale for these fuel types in transportation is mainly for the environment. Hydrogen has zero impact on the environment, unlike LPG and CNG which has little or no impact on the surrounding. Hydrogen still ranks last when all other factors were considered. Thus, LPG vehicles remain the best option for Nigeria's transportation mode. The Nigerian Road having a total of 11,760,871 vehicles (Nigeria Bureau of Statistics, 2018) is a major contributor to air pollution and global warming. This clear impact on human health and the ecosystem must be eradicated by regulatory bodies because of the increasing growth rate and the demand for mobility. In other to substantially curb GHG, emission and improvement standards must be implemented.

Economic value: The cost of fuel per liter, energy content, and maintenance cost data in table 1 were used to make decisions about the economic value. Autogas generally has a lower cost of supply and infrastructure per energy content than fossil fuels. It's also cost-effective because it thrives on existing plants and equipment used for the production, refining, and storage of LPG. All things being equal, the retail price of LPG is generally lower than Hydrogen, Butane, CNG, gasoline, and diesel, making it easily accessible. This is not the case for CNG because it requires it to be delivered in bulk to major centers. The major issue is the investment capital for downstream depots or stations and policies that implements the use of dual-fueled engines from original equipment manufacturers.

Safety: The flammability of gas fuels was used as the basis for safety considerations. Flammability is directly related to the composition of the fluid and a lower flammability percentage guarantees a lesser tendency for the fuel to be ignited. The low flammability of LPG and CNG makes them a safer alternative than other fuels. The government must play a major role in ensuring quality assurance of the fuel and maintenance of storage and refilling equipment.

CONCLUSION

Transportation is an important sector in the socio-economic development of Nigeria and the world at large. The growth of this critical sector is solely driven by increasing energy. The passenger, vehicle fleets, trucks, trains, ships, aircraft, etc., are elements of transportation that consume the energy provided by gas fuels or auto fuels. With the increasing demand for mobility, an efficient transport system must provide a healthy, safe, and wealthy economy. The environmental impact must be reduced to within net zero sustainable goals which is the aim for every investment in green energy. In Nigeria, there is a huge energy deficit. Transiting to renewables will require heavy investment, as such, it is best to transit using her abundant gas reserves which is cleaner compared to PMS, and AGO. A transition from blended to non-blended should be adopted in transportation to minimize air pollution in high-population areas. Policies and incentives that favors the use of Autogas fuel for transportation should be enacted by the government. This will cause a progressive shift in line with energy utilization and sustainable goals. The result of this study validates the environmental, economic, and safe benefits of using Autogas as an alternate fuel source. LPG was ranked the highest, followed by CNG, LNG, butane, and hydrogen. Hydrogen ranked last possibly due to its high flammability and fuel cost per GGE.

Based on the findings of this study, there are several potential ways forward for further research and exploration in the field of transportation energy use and the adoption of gaseous fuels in Nigeria. Suggested scope of future studies may include:

- ✓ Research focus on factors such as energy efficiency, availability, infrastructure requirements, technological feasibility, and compatibility with existing vehicles and transportation systems.
- ✓ Investigating the policy and regulatory frameworks necessary to support the transition to gaseous fuels in transportation. This could involve examining successful case studies from other countries that have implemented favorable policies and incentives to promote the use of gaseous fuels. Additionally, studying the potential economic impact and feasibility of implementing such policies in the Nigerian context would be beneficial.
- ✓ Explore the integration of renewable energy sources with gaseous fuels. This could involve investigating the feasibility of producing renewable gas fuels such as bio-LPG or exploring opportunities for using renewable energy for the production and distribution of gaseous fuels.

By conducting these suggested further studies, researchers can gain a more comprehensive understanding of the opportunities, challenges, and potential benefits associated with the adoption of gaseous fuels in the transportation sector of Nigeria. These studies can inform policymaking, technological advancements, and investment decisions, ultimately contributing to a more sustainable and efficient transportation system. Therefore, policymakers should enact supportive policies and incentives to encourage the adoption of gaseous fuels, particularly Autogas, in Nigeria's transportation sector, aiming to minimize air pollution and promote sustainable energy utilization.

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APPENDICES

Appendix A

Table 4: Total Final Consumption(IEA,2019)

Years	Coal	Oil products	Natural gas	Biofuels and waste	Electricity
1990	1618	265775	29993	2157703	28336
1995	516	302018	30990	2453384	33970
2000	77	403570	40576	2804648	31115
2005	206	509927	117807	3226876	61830
2010	980	519361	50716	3809138	74376
2015	1316	761815	157568	4263486	90151
2019	1409	867471	157234	4549953	98186

Table 5: National Average Retail Fuel Prices on an Energy-Equivalent Basis (Alternative Fuel Price Report, 2022)

Fuel/Cost	$/GGE	$/DGE	$/MBtu
Gasoline	$4.70	$5.31	$41.12
Diesel	$5.02	$5.64	$43.82
CNG	$2.76	$3.12	$24.15
LNG	$3.15	$3.54	$27.51
Ethanol	$5.10	$5.77	$58.22
Propane	$5.19	$5.84	$62.16

Appendix B

TOPSIS optimization results;

Step 1

```
[[  1.    0.      5.91  120.7    1.    75.  ]
 [  1.    2.75   2.76  53.6     1.    16.4 ]
 [  1.    2.75   3.54  47.26   2.    10.4 ]
 [  1.    3.      5.19   53.     1.    10.  ]
 [  2.    3.03   5.08  54.66   1.    8.41]]
```

Step 2

```
[[0.35355339 0.         0.56916504 0.75627289 0.35355339 0.95459349]
 [0.35355339 0.4765101  0.26580296 0.33584281 0.35355339 0.20873778]
```

[0.35355339 0.4765101 0.34092119 0.29611812 0.70710678 0.1323703]
[0.35355339 0.5198292 0.49982514 0.33208337 0.35355339 0.12727913]
[0.70710678 0.52502749 0.48923154 0.34248448 0.35355339 0.10704175]]

Step 3

[[0.05303831 0. 0.08156951 0.10838474 0.05066927 0.25776602]
[0.05303831 0.07148366 0.03809337 0.04813109 0.05066927 0.05636484]
[0.05303831 0.07148366 0.04885889 0.04243797 0.10133854 0.03574355]
[0.05303831 0.07798218 0.07163211 0.04759231 0.05066927 0.0343688]
[0.10607662 0.078762 0.07011389 0.04908293 0.05066927 0.02890416]]

Step 4

[0.10607662 0.078762 0.08156951 0.04243797 0.10133854 0.25776602] [0.05303831 0. 0.03809337 0.10838474 0.05066927 0.02890416]

Step 5

[0.12622546 0.2189028 0.23071627 0.23539898 0.23477758] [0.23295477 0.09743975 0.11040353 0.10455453 0.11644112]

Step 6

[0.35142653 0.69198025 0.67634968 0.69244463 0.66846549] [0.64857347 0.30801975 0.32365032 0.30755537 0.33153451]

best_distance [0.23295477 0.09743975 0.11040353 0.10455453 0.11644112]

worst_distance [0.12622546 0.2189028 0.23071627 0.23539898 0.23477758]

worst_similarity [0.35142653 0.69198025 0.67634968 0.69244463 0.66846549]

rank_to_worst_similarity [1, 5, 3, 2, 4]

best_similarity [0.64857347 0.30801975 0.32365032 0.30755537 0.33153451]

rank_to_best_similarity [4, 2, 3, 5, 1]