Techno-Economic Analysis of Gas Monetisation Technologies Using Topsis

Okoli Nnanna O[1], Nwaozuzu Chijioke[2], Nteegah Alwell[3], Onyejekwe Ifeanyi M[4]
[1,2,3] *Emerald Energy Institute, UNIPORT*
[4] *Department of Petroleum Engineering, FUTO*

Abstract: **This study conducted a techno-economic comparative analysis of gas monetization technologies (Liquefied Natural Gas (LNG) and Gas to Liquid (GTL)) using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). In the course of the study, the pros (strengths) and cons (constraints/limitations) of the different gas monetization options were discussed, and the economics and technical viabilities of LNG and GTL were ascertained. Technically, five attributes/criteria (volume, distance, cost, time and environmental impact) were considered. From the TOPSIS analysis and results, the technically best technology considering volume, distance, cost, time and environmental impact was GTL with a score of 0.505. This LNG had a score of 0.495. From the analysis, the GTL performed better under the most significant criteria (cost and environmental impact), it also performed better than LNG under time of delivery. Whereas, the criteria where LNG performed better (volume and distance), their weights are not too significant to make it emerge ahead of GTL as a better technology technically. Hence, from the study findings, it can be deduced that GTL performed better technically than LNG.**

Keywords: **GTL, LNG, TOPSIS, Gas Monetisation.**

I. INTRODUCTION

Nowadays, the continual and indiscriminate fluctuations in the price of oil, coupled with the significant decline in reserves, as well as the new environmental attitude expressed by various national governments about the existing high levels of air pollution, have led to the exploitation of a cleaner and more economically attractive fuel, namely the natural gas (Sydney & Richard, 2003).

In contrast to petroleum or coal, natural gas can be used directly as source of primary eco-friendly energy that causes less carbon dioxide and nitrogen oxide emissions (greenhouse gases). Thus, natural gas has proven to be a strategic commodity that augments current global energy supplies and, to some extent it alleviates some of the possible consequences of using petroleum and petroleum derivatives (Rajnauth*et al*., 2008).

In recent decades, the global monetization of natural gas has transformed the nature of the energy economy. Once only burned off as an annoying byproduct of oil recovery, natural gas has become a highly traded commodity. The resource has several advantageous characteristics: it serves as a staple fuel for many technologies, has been relatively abundant and within physical and technological limits for extraction, and features a favourable chemistry that releases less carbon dioxide upon combustion than oil or coal (Nweke & Dosunmu, 2015).The efficient and effective transportation of natural gas from producing areas (Source Point) to consumption regions (Demand Points) requires an extensive and elaborate transportation system (Guo& Ali, 2005). Several variables play significant role in the transportation system. Some of the factors affecting the type of gas transportation used include gas reserves, time frame to monetize the gas, the distances to the markets, investments and infrastructure available and gas processing. (Jack, 1982).

The possible ways of transporting natural gas to markets are Pipelines, Liquefied Natural Gas, Compressed Natural Gas, Gas to Solids (hydrate), Gas to Liquids, Gas to Wire and other gas to commodity methods (Campbell, 2004).Some of these methods become uneconomical when measured against variables such as gas reserves, time frame to monetize the gas, the distances to the markets, investments requirement, infrastructure available and gas processing needs (Nweke&Dosunmu, 2015). These issues become even more important with the development of stranded gas reserves i.e. meaning that it has no current market, such as in the many on- or offshore fields where there is no pipeline, or when flaring of associated gas is prohibited (Albers *et al*., 1986).

The Economics of Natural gas transportation is affected by a host of factors such as Geography, Distance to demand points, prevailing natural gas price, transport technology deployed, prevailing economic policies and government regulations. The impacts of these factors on the methods of gas transportation vary widely and are usually not clearly defined in previous studies.With adequate data for a given scenario, it is reasonable that optimal decisions can be found. Thus, this paper explored the use of other technologies for Gas transportation from source points to demand points especially where distance and demand do not justify an investment in a gas pipeline. The study focused on the decision to monetize using only two of the available options: GTL and LNG and in reaching a decision to which technology to deploy, a techno-economic multi-criteria comparative analysis approach was applied using the Technique for Order of Preference by Similarity to Ideal Solution.

II. METHODOLOGY

In this paper, two gas monetization technologies, which are:GTL and LNG were technically evaluated. The best option considering all the prevalent operating conditions and the cost of decommissioning was proposed for efficient gas monetization.

The analysis, evaluation and comparison of the gas monetization technologies were done via detailed review and the use of a multi-criteria decision making tool- TOPSIS. The technical factors considered included the Environmental impact, volume, distance, and time.

In this study, most of the data were gathered from expert opinions and the existing literature. The merits and demerits, strengths and limitations of the gas monetization technologies were gotten from the literature. Expert opinions/judgements, detailed desktop review and literature review of materials, past research works and articles were also used in gathering data for this study.

In the paper, TOPSIS Multi-Criteria Decision Making Analysis tool was used to develop an effective decision matrix in this study. TOPSIS method is based on the concept that the chosen alternative should have the shortest distance to Positive Ideal Solution (PIS) (the solution which maximizes the benefit criteria) and the farthest distance to Negative Ideal Solution (NIS).

Technique of Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS tool is dependent on the idea that the chosen option must have the least geometric distance from the positive ideal solution and the farthest geometric distance from the negative ideal solution (Assari*et al*., 2012). It analyzes a set of options by assigning weights on each factor for comparison, normalizing the weights for each factor and computing the geometric distance between each option and the ideal positive alternative. TOPSIS assumed the factors are monotonically increasing or decreasing (Beg and Rashid, 2014). Normalization is usually needed because the factors are quite unharmonious which is common in a multi-criteria problem. TOPSIS allows for trade-off between the criteria, where a negative outcome in one criteria can be cancelled out by a positive outcome in another criteria (Greene *et al*., 2011). This provides a more realistic form of modeling and comparative analysis.

TOPSIS considers three sets of attributes or criteria:

i. Qualitative benefit attributes
ii. Quantitative benefit attributes
iii. Cost attributes

With TOPSIS two artificial options are hypothesized:

i. Ideal alternative: the one with the best attribute values.
ii. Negative ideal solution: the one with the worst attribute values.

TOPSIS chooses the option that is the closest to the ideal solution and farthest from negative ideal solution (Huang *et al*., 2011).

TOPSIS Algorithm

Figure 1 depicts the steps undertaken in TOPSIS analys is.

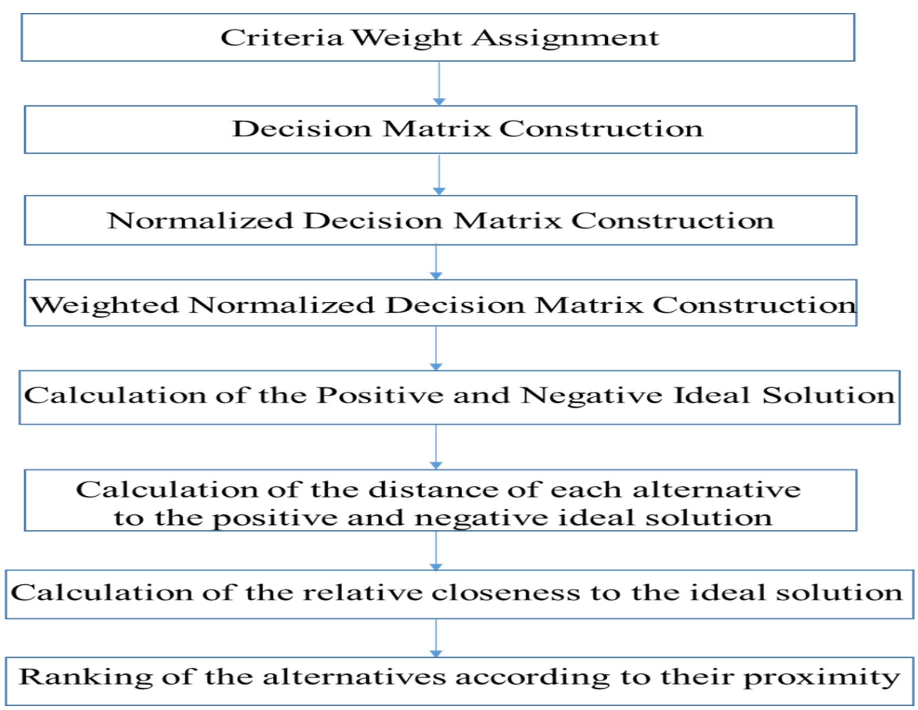

Figure 1: TOPSIS Algorithm

Input to TOPSIS

TOPSIS takes into consideration m number of alternatives to choose from and n criteria to base the choice on and one must score each option against the corresponding criterion.

Assume x_{ij} score of alternative i with respect to criterion j, a matrix X = (x_{ij}) m×n matrix is formed. J is the set of positive attributes (the more the better) and J' is the set of negative attributes (the less the better). Each factor can be scored certain points on a scale of 0-10 0r 0-100 by the experts (Assari*et al*., 2012).

Steps for TOPSIS (Zavadskas*et al*., 2006)

Step 1: Develop a normalized decision matrix.

This step converts a number of attribute dimensions into dimensionless attributes, which allows for comparisons across criteria.

The weights or scores can be normalized using the formula below:

$rij \ = x_{ij} / \left(\Sigma x_{ij}^2\right)^{\frac{1}{2}}$ fori = 1…m; j = 1, …, n

Step 2: Develop the weighted normalized decision matrix.

Given a set of weights for each attribute w_j for j = 1,…n. Individual column of the normalized decision matrix is multiplied by its corresponding weight.

An element of the new matrix is formed as:

$$v_{ij} \ = \ w_j r_{ij}$$

Step 3: Determine the ideal and negative ideal solutions.

- Ideal alternative.

$A^* = \ \{v_1^* \ldots v_n^*\}$, where

$$v_j^* = \ \{ \ max \ (v_{ij}) \ if \ j \ \in J \ ; \ \ min \ (v_{ij}) \ if \ \ j \ \in J\}$$

- Negative ideal solution.

$A^{'} \ = \ \{v_1^{'} \ldots v_n^{'}\}$, where

$$v^{'} \ \ = \ \{ \ max \ (v_{ij}) \ if \ j \ \in J \ ; \ \ min \ (v_{ij}) \ if \ \ j \ \in J'\}$$

Step 4: Estimate the separation measures for each alternative.

The separation from the ideal alternative is given as:

$S_i^* = \ \left[\Sigma\left(v_j^* - \ v_{ij}\right)^2\right]^{\frac{1}{2}}$ i = 1, …, m

Similarly, the separation from the negative ideal alternative is:

$S_i^{'} \ = \ \left[\Sigma\left(v_j^{'} - \ v_{ij}\right)^2\right]^{\frac{1}{2}}$ i = 1, …, m

Step 5: Calculate the relative closeness to the ideal alternative C_i^*

$C_i^* = S_i^{'} / (S_i^* + S_i^{'})$, $0 < C_i^* < 1$

Select the option with C_i^* closest to 1.

Step 6: Rank the preference order.

III. RESULTS AND DISCUSSIONS

In the oil industry, cutting down cost while having a less negative environmental impact has remained the key for decades. To start the analysis with TOPSIS, pairwise comparison of the criteria was done. To achieve this, a key question was asked: how important is one criterion compared to another? To answer this question, expert judgements were sought in addition to the detailed desktop/literature review conducted. Also, for each of the alternatives considered (GTL and LNG), how they perform against these criteria was weighted/scored. Based on this, the following decisions were taken with respect to the importance of one criterion relative to the other:

1. If volume = x; distance=2x, cost=4x, environmental impact=4x. This implies that for this present analysis, distance is two times more important than volume, cost is four times more important than volume, and environmental impact is four times more important than volume. This is so because, based on the researcher’s judgement and those of the experts consulted in the study, cost and environmental impact are the most important factors the industry considers for any technology and if distance and volume are weighed side by side, the capacity of a technology to convey a product from point A to point B is more important than the volume it can convey. It is more reasonable to convey 100 barrels of oil or 1000 SCF of compressed gas twice with one technology and still get to the desired discharge point than conveying the entire volume but cannot get to the discharge point. Sequel to this, the distance as a criterion is more important than the volume. Also, if environmental impact and volume are weighed side by side, the ability to convey a product with minimal environmental impact is more important than being capable to convey large volumes of a product but with high negative impact to the environment.
2. If time=x; volume=2x, cost=4x, environmental impact=4x. Similar to the points made above, volume is considered two times more important than time, cost is four times more important than time and environmental impact is also four times more important than time. If volume and time are weighed side by side, it is more desirable to convey the needed volume of a product in one month from point A to B, than to have a technology which can go from point A to B in one day but cannot convey the needed volume of the product due to cost implications or any other reasons. As stated earlier, cost and environmental impact are superior to any other criterion in this present study as the end goal of the industry with respect to any technology is to

break even and increase profit margin while keeping the environmental impact very minimal. Also being able to convey a product with less environmental impact is more important than how fast the product can be conveyed.

3. If distance=x; cost=4x, time=2x, environmental impact=4x. In this case, any technology that will take less amount of time for equal volumes of product from point **A** to **B** is the preferred option. Therefore, time is two times more important than distance. Also, the ability to convey a product from **A** to **B** with little or no environmental impact is more important that the distance coverable by the technology.
4. If time=x; volume=2x, cost=4x, environmental impact=4x. Here, the ability to convey the desired volume is more important than the time it takes to go from **A** to **B**.
5. If environmental impact=x, cost=x. As mentioned earlier, the industry will choose a technology which offers more profit and less cost and with a less environmental impact.

The implication of the assigned importance is that 2x implies the criterion is moderately more important than the criterion it is being compared with, while 4x implies that the criterion is strongly more important than the criterion it is being compared with. These comparative weighting, influenced the weights/scores in Table 1.

Table 1 shows that under the volume of product that can be conveyed at any specific time, the LNG ship is a better technology (this is because the LNG has the largest volume capacity compared to GTL). For the maximum transportation distance possible, LNG ship is also a better technology (this is also because the LNG can be used for distances of over 300km economically more than any other technology). For cost including the capital, operating and decommissioning costs, the GTL is not just more economical than LNG, it is also more profitable), considering the delivery time, GTL is the better. This is due to the fact that mobile GTL is now available. And finally, considering the environmental impact, the GTL also came out as a better option than LNG (this is because GTL has an option to be piped, except for rare cases of pipeline vandalism, the pipeline technology has the least probability for spillage or discharge of conveyed products to the environment).

Applying TOPSIS to this study; m is 2 alternatives/options GTL and LNG, n is 5 attributes/criteria (volume, distance, cost, time and environmental impact), w_j is set of weights for each criteria as shown in Table 1. x_{ij} is score of option i with respect to criterion j as shown in Table 2. J is set of benefit attributes: more volume, more coverable distance, less cost, less time and less environmental impact.

The normalized decision matrix $rij = x_{ij} / \left(\Sigma x_{ij}^2\right)^{\frac{1}{2}}$ 1

is presented in Tables 3 and 4.

The weighted normalized decision matrix $v_{ij} = w_j r_{ij}$ 2

is constructed by multiplying each column of the normalized decision matrix (Table 4) by its corresponding weight (Table 1) and

the new matrix $rij = x_{ij} / \left(\Sigma x_{ij}^2\right)$ 3

is constructed as presented in Table 5. A set of maximum values for each factor (from Table 5) also referred to as the ideal Alternative

$A^* = \{v_1^* \ldots v_n^*\}$ 4

is determined as presented under step 3 below. In the same way, a set of minimum values for each factor (from Table 5) also referred to as the Negative ideal Alternative

$A^{'} = \{v_1^{'} \ldots v_n^{'}\}$ 5

is determined as presented in step 3.

The separation from the ideal Solution I,

$S_i^* = \left[\Sigma\left(v_j^* - v_{ij}\right)^2\right]^{\frac{1}{2}}$ 6

is determined as presented in Table 6 and the outputs are presented under step 4a. Also, the separation from the negative ideal Solution,

$S_i^{'} = \left[\Sigma\left(v_j^{'} - v_{ij}\right)^2\right]^{\frac{1}{2}}$ 7

is determined as presented in Table 7 and the outcomes are presented under step 4b.

The relative closeness to the ideal solution, $C_i^* = S_i^{'} / (S_i^* + S_i^{'})$ 8

is calculated and the outputs are as presented in Table 8.

Table 1 below presents the weights scored against each of the criteria on a scale of 1-10 based on their relevance to the analysis. The weights shown here are average of the scores from experts' judgements (see also Figure 2).

Table 1: Weights scored to the factors

Criteria	Score	Score Rating Scale
Volume	5	(10 Implies Highly Relevant, 1 Implies Not Relevant)
Distance	7	
Cost	9	
Time	3	
Environmental Impact	9	

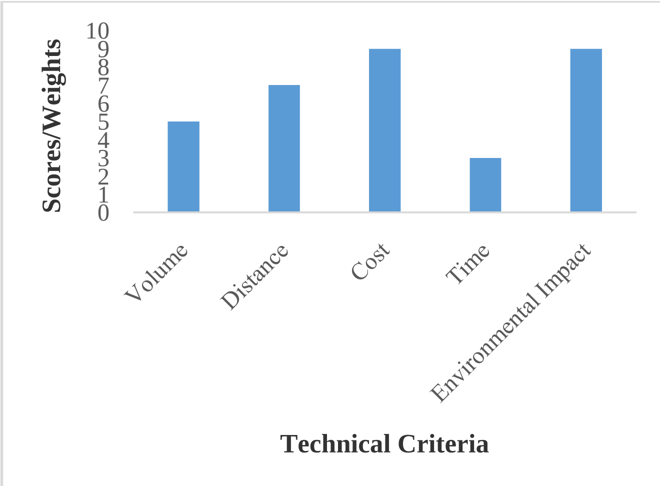

Figure 2: Scores of the Technical Factors for TOPSIS Analysis

The alternatives to be compared include:

Option 1: Gas to Liquid technology (GTL)

Option 2: Liquefied Natural Gas (LNG)

The decision matrix for the alternative scores with respect to the criteria is presented in Table 2 (see also Figure 3):

Note: A rating of 1 implies excellent per the factor in consideration, while a rating of 0 implies very poor.

Table 2: x_{ij} = rating of alternative i with respect to factor j

Criteria	GTL	LNG
Volume	0.7	0.9
Distance	0.6	0.9
Cost	0.8	0.6
Time	0.8	0.6
Environmental Impact	0.8	0.6

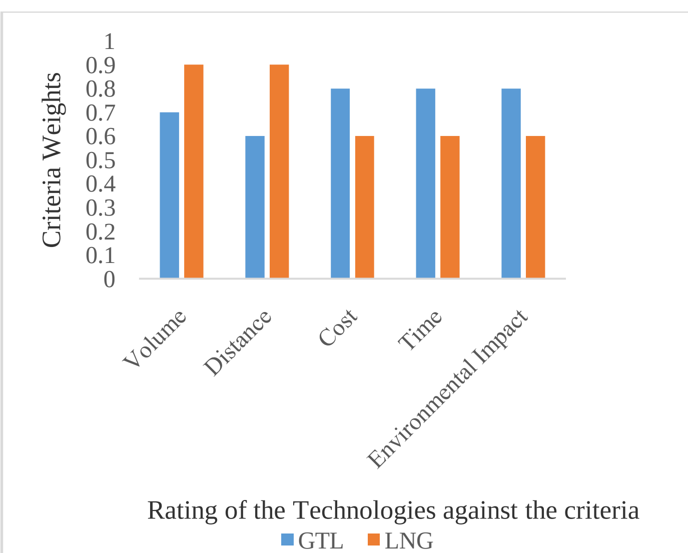

Figure 3: Scores of the technologies against the criteria

Analyzing with TOPSIS yields:

Step 1: Standardizing the decision matrix

This step turns the scores dimensionless by dividing each row of the decision matrix by root of sum of square of the row's scores. The result of this is presented in Table 4:

Table 3: Standardized the decision matrix

Criteria	GTL	LNG	$(\Sigma x_{ij}^2)^{\frac{1}{2}}$
Volume	0.7	0.9	1.14018
Distance	0.6	0.9	1.08166
Cost	0.8	0.6	1
Time	0.8	0.6	1
Environmental Impact	0.8	0.6	1

Step 1 (b): divide each row by $(\Sigma x_{ij}^2)^{\frac{1}{2}}$ to obtain r_{ij} which is the normalized decision matrix as presented in Table 4 below.

Table 4: The normalized decision matrix

Criteria	GTL	LNG
Volume	0.5385	0.7894
Distance	0.5128	0.8321
Cost	0.8	0.6
Time	0.8	0.6
Environmental Impact	0.8	0.6

Step 2: Construct weighted standardized decision matrix by multiplying the factor weight (as shown in table 1) with the corresponding score provided in table 4 above. The weighted standardized decision matrix is as shown in table 5 below:

Table 5: The weighted normalized decision matrix

Criteria	GTL	LNG
Volume	2.692	3.947
Distance	3.5897	5.8243
Cost	7.2	5.4
Time	2.4	1.8
Environmental Impact	7.2	5.4

Step 3: Determine ideal alternative and negative ideal alternative

A set of maximum values for each factor across the rows is the ideal alternative while a set of minimum values for each factor across the row is the negative ideal alternative.

Ideal alternative A: {3.947, 5.8243, 7.2, 2.4, 7.2}*

Negative ideal alternative A': {2.692, 3.5897, 5.4, 1.8, 5.4}

*Step 4: Determine separation from ideal alternative, S_i**

Step 4 (a): calculate separation from ideal solution A* = {3.947, 5.8243, 7.2, 2.4, 7.2} and $S_i^* = \left[\Sigma\left(v_j^* - v_{ij}\right)^2\right]^{\frac{1}{2}}$ for each column. This is computed and results are presented in table 6.

Table 4.6: The ideal alternative

Criteria	GTL	LNG
Volume	1.575	0
Distance	4.993	0
Cost	0	3.24
Time	0	0.36
Environmental Impact	0	3.24
$\Sigma\left(v_j^* - v_{ij}\right)^2$	6.568	6.84
$S_i^* = \left[\Sigma\left(v_j^* - v_{ij}\right)^2\right]^{\frac{1}{2}}$	2.563	2.615

$$S_i^* = \left[\Sigma\left(v_j^* - v_{ij}\right)^2\right]^{\frac{1}{2}} = \{2.563, 2.615\}$$

Step 4 (b): calculate separation from negative ideal alternative A' = **{**2.692, 3.5897, 5.4, 1.8, 5.4**}** and $S_i' = \left[\Sigma\left(v_j' - v_{ij}\right)^2\right]^{\frac{1}{2}}$ for each column as presented in table 7 below.

Table 7: Separation from the negative ideal solution

Criteria	GTL	LNG
Volume	0	1.575
Distance	0	4.993
Cost	3.24	0
Time	0.36	0
Environmental Impact	3.24	0
$\Sigma\left(v_j^* - v_{ij}\right)^2$	6.84	6.5685
$S_i^* = \left[\Sigma\left(v_j^* - v_{ij}\right)^2\right]^{\frac{1}{2}}$	2.615	2.563

$$S_i' = \left[\Sigma\left(v_j' - v_{ij}\right)^2\right]^{\frac{1}{2}} = \{2.615, 2.563\}$$

Step 5: Compute the relative closeness to the ideal solution $C_i^* = S_i'/(S_i^* + S_i')$

The matrix of the closeness to the ideal solution is shown in table 8 below:

Table 4.8: The relative closeness to the ideal solution

Criteria	GTL	LNG
Si*	2.563	2.615
Si'	2.615	2.563
Si*+Si'	5.178	5.178
$S_i'/(S_i^* + S_i')$	0.505	0.495

From the TOPSIS analysis and results, the technically best technology considering volume, distance, cost, time and environmental impact is GTL with a score of 0.505. This LNG has a score of 0.495 (see Figure 4).

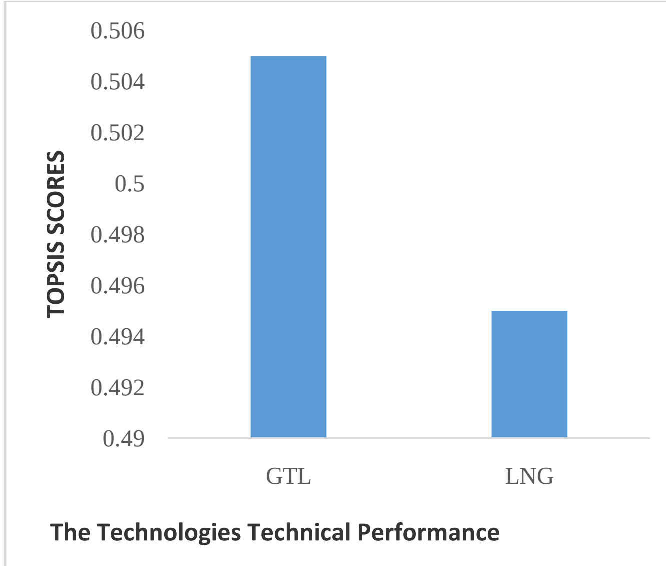

Figure 4: TOPSIS Rating of the Technologies

IV. CONCLUSION

From the analysis, the GTL performed better under the most significant criteria (cost and environmental impact), it also performed better than LNG under time of delivery. Whereas, the criteria where LNG performed better, their weights are not too significant to make it emerge ahead of GTL as a better technology technically.

Hence, from the study findings, it can be deduced that GTL performed better both economically and technically than LNG.

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