Wat.Ener.Food.Env.J 4, No. 1,31-41 (2023) 

Water, Energy, Food and Environment Journal
*An International Journal*

http://dx.doi.org/10.18576/wefej/040103

# The Russian-Ukrainian War and its Role in Securing New Sources for Liquified Natural Gas

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Received: 5 Aug. 2022, Revised: 18 Sep. 2022, Accepted: 21 Oct. 2022.
Published online: 1 Jan. 2023.

**Abstract:** The purpose of this research is to build an economic model that can investigate the possibility of finding an optimal solution to the transportation problem that can bring into finding new sources for fulfilling Liquified Natural Gas (LNG) requirements with shorter distances and lower transportation costs. A transportation model named the North-West Corner Model that deals with the transfer of goods from various sources (points of supply) to various points of demand (destinations) was adopted in this study. Scheduling shipments from sources to destinations is the goal in order to reduce the overall transportation expenses. It is a strategy used to solve the transportation model problem structure in linear programming. Our result shows that the model is reliable for implementation since it provides a lower transportation cost - the overall transportation cost obtained by the model is reduced by (-26.36%). It is concluded that if the concern countries apply the solution reached by our model, they will enjoy securing new locations for their LNG requirements, lower delivery costs with less distances, and faster delivery time.

**Keywords:** Natural Gas, Economic Analysis, Transportation Cost, North-West Corner Model, Optimization.

## 1 Introduction

Natural gas is the energy source that has grown the fastest since the beginning of the 1970s, and this trend is expected to continue as global demand for clean source of energy rises. In its market report, the International Energy Agency (IEA) projected that global natural gas consumption is projected to expand at an average annual rate of 0.8% from 2022 to 2025, reaching roughly 4,240 billion cubic meter in 2025 as the industrial sector continues to use the most gas, which accounts for nearly 60% of the increase in worldwide gas demand during the mentioned period.

Currently natural gas consumption is under significant pressure as a result of the present high price and tight supply scenario, which developed in the second half of 2021 and further increased following Russia's invasion of Ukraine in February 2022. It is anticipated to provide slightly negative growth in 2022, followed by modest improvements in consumption in the years that follow. As a result, the world gas consumption decreases by 0.5% in 2022 before gradually increasing over the ensuing years to reach 1.5% in 2025, according to the IEA.

### *1.1 Research Objectives*

- To examine and analyse the current trade of Liquefied Natural Gas (LNG), prices, and transportation costs in the world.
- To examine and analyse the possibility of developing new sources for securing LNG requirements with shorter destinations and lower delivery costs.
- To build a transportation model that can supply LNG natural gas with the least destinations and delivery costs.

### *1.2 Research Questions*

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- What other alternative locations that can supply Liquified Natural Gas (LNG) to the rest of the world with the least destinations and the lowest transportation cost.
- What is the model/models that would provide optimal solution?
- Does the model provide better result compared with current transportation cost?

### *1.3 Problem Statement*

Europe continues to be largely reliant on Russian gas, which meets 40% of its requirements, but invasion of Russia to Ukraine last spring has caused the west to impose wave of sanctions on Russia in reaction to this invasion. Now Europeans are concerned that Russia would use it as payback for sanctions. The question is that, would Russia stop its commitment? or would it continue supplying gas to Europe specially to satisfy long-term contracts and commitments?

These behaviours, in fact, brought an alert to all users of natural gas that it is time to find other sources (suppliers) for securing their gas requirements in the future. These new sources would be more attracted if incorporated with shorter distances and lower transportation costs.

## 2 Literature Review

Numerous researchers have put forth a lot of effort over the course of human history to discover a solution to the transportation issue and reduce the cost of transportation. A plausible initial basic solution using the simplex method to a transportation problem was obtained by Dantzig (1951), which Charms and Cooper then dubbed the North-West Corner Rule (NWCR) in (1954). Later, several modifications to the transportation model and procedures were developed and became one of the most effective techniques for locating the best answers after being used by many scientists and researchers.

M. SHARIF UDDIN, SAYEDUL ANAM, ABDUR RASHID[1] AND AMINUR R. KHAN (2011) created a network model to determine the shortest path, and the north-west corner rule to determine the least expensive route. Ashraful Babu, Abu Helal, Mohammad Sazzad Hasan, and Utpal Kanti Das (2013) suggested the "Lowest Allocation Method (LAM)" as a new algorithm to identify workable solutions for transportation problems. The results of their model were compared to models such as the North-West Corner Rule (NWC), Least Cost Method (LCM), and Vogel's Approximation Method (VAM), among others. VAM is the most effective method for locating workable solutions. They concluded that their suggested method needed less iterations than other algorithms to achieve a workable answer that was near to the ideal one. Shilpa Parkhi, Jagadeesh D, R. Kumar (2014) discussed the optimization network to optimize the logistic cost of the retail supply chain. They analysed different factors for reaching the best solution and concluded that concentrating on these factors would decrease transportation cost. Adwell Mhlanga, Immaculate S. Nduna, Dr Florence Matarise, Albert Machisvo (2014) in their study "Innovative application of Dantzig's North – West Corner Rule to solve a transportation problem" employed the technique but questioned its high number of repetitions and suggested that the rows or columns be heavily modified before using the procedure. Sindh Univ. Res. Jour (2016) employed a modified version of the North-West Corner Method to locate the best answer for their transportation model. The results of this model were comparable to those of the North-West Corner Method, although from a temporal perspective, the Modified North-West Corner is more effective than the NWCM.

Shraddha Mishra (2017) employed the Northwest Corner Method, the Minimum Cost Method, and Vogel's Approximation Method as three linear programming models to identify the best optimal solution for a transportation problem. His finding is that the decision-maker may select the outcome from among the three models that produces the best results, and this will define the quantity of units that will be delivered from source to destination. Maranata Pasaribu (2019) used the North-West Corner method to calculate the optimal shipping cost incurred by an Indonisian company when shipping its products to destinations. The author concluded that the technique is useful and easy in calculating these costs. When solving numerical instances for optimal solutions and determining the least solution using VAM, S. Gangatharan, P. Murugan (2019) used decagon numbers which converted to fuzzy values utilizing the robust ranking method. They concluded that because the Least Cost Method takes cost into account when allocating resources, it is thought to give more optimal results than the North-West Corner. ADAMU ISAH KAMBA, SULEIMAN MANSUR KARDI AND YUNUSA KABIR GORIN DIKKO (2020) employed two transportation models, the North-West corner method, and the Least Corner Method, to calculate a Furniture Factory's Minimum Transportation Cost. As a result of their research, logistic managers were advised to utilize the Nort-West Corner approach to acquire the least transportation costs when compared to the least corner method. Fibi Putra, Humaira Purba, Indah Anggreani (2020) used two models, North-West Corner and Stepping-stone to find the optimal distribution of goods and transportation costs for common products. They concluded that the North-West method provided better cost reduction result compared with steppingstone.

Utilizing the North-West Corner Rule, R.M. Ranasinghe and R.M.K.T. Rathnayaka (2021) created a program to identify the Initial Basic Feasible solution to the transportation challenge (NWCR). They concluded that this suggested program is more beneficial for decision-makers who frequently deal with imbalances between supply and demand. Additionally, this way of applying the NWCR method is time-saving and reliable; as a result, the final answer has a greater level of reliability without human errors than when the method is applied manually.

| | *To==>* | *j1* | *j2* | *j..+n* | *Total Supply* |
|---|---|---|---|---|---|
| *From* | *i1* | *Ci1j1* | *Ci1j2* | *Ci1jn* | *i1* |
| | *i2* | *Ci2j1* | *Ci2j2* | *Ci2jn* | *i2* |
| | *i.. +m* | *Cimj1* | *Cimj2* | *Cimjn* | *im* |
| | *Total Demand* | *j1* | *j2* | *jn* | |

## 3 Research Methodology & Data

A linear programming technique utilizing QM for Windows will be used to determine the initial workable solution to the transportation problem is known as the North-West Corner Rule. The basic variables are chosen from the very left corner, hence the name North-West corner. Here is a calculator that estimates the minimum shipping costs using the north-west corner method. The calculator tool will automatically update us with the minimal transportation cost when entering the array values and complete out the matrix form.

*Where: -*

*Cij* = transportation cost from origin to destination.
*i* = 1, 2, …., m (supply at origin)
*j* = 1,2, …., n (demand at destination)

This approach deals with the transfer of goods from various sources (points of supply) to various points of demand (destinations). Typically, we have a certain number of commodities available at each source and a set amount of goods needed at each destination. Scheduling shipments from sources to destinations is the goal of this issue in order to reduce overall transportation expenses. It is a strategy used to solve the Transportation Model problem structure in linear programming. This strategy, where the variables are chosen from North to West corner, that is, top to left corner, aids in finding a fundamentally workable solution for the transportation model.

Data for LNG demand, supply, and transportation costs were collected from different sources such as Statistical Review of World Energy, US Department of Energy, Energy Information Administration (EIA), and statista.com.

## 4 Analyses

### *4.1 Prices of Natural Gas*

Prices for LNG are often stated in US dollars and USD per million BTU (MMBTU). Free on board (f.o.b.) and delivered ex-ship (d.e.s.) are two ways that prices might be expressed. Today's trades often involve f.o.b. contracts, which provide purchasers more freedom to exchange surplus LNG cargos. Due to the strong demand and low domestic supply in the pacific basin, prices are often higher than in the Atlantic basin. While the price of a basket of alternative fuels is used to determine the price of LNG in the European and Asian markets, the Henry Hub price is used to determine the price in the North American market. Prices for importing LNG declined during the past 10 years, declining at an average rate of (3.6%) during the period, from $7.57 per million BTU in 2010 to $7.3 per million BTU in 2019.

In the mid of 2022 and due to aggressive imports of liquefied natural gas by numerous European countries to replenish inventories and make up for lower Russian gas flows, European natural gas reached an all-time high of $70/mmbtu in August 2022, figure (4). Prices rose significantly both in Japan and the United States. Then, when inventories filled and consumers cut back on consumption in reaction to rising prices and warmer-than-normal weather, European prices began to decline. Prices for natural gas are anticipated to decline in 2023 as demand declines. it challenging to restock in 2023.

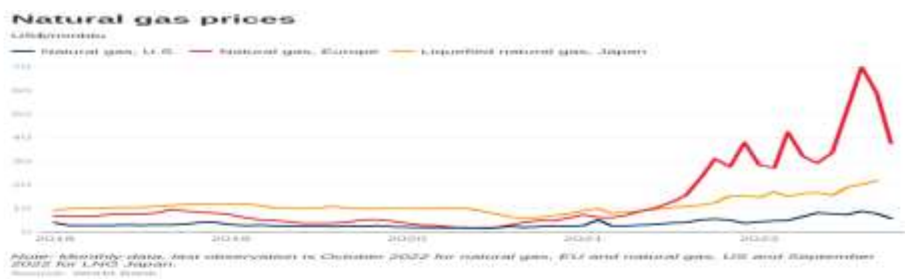


**Fig.1:** Natural Gas Prices.

Source : https://www.iea.org/data-and-statistics/charts/lng-import-prices-in-selected-countries-2010-2019
https://blogs.worldbank.org/developmenttalk/commodity-markets-outlook-nine-charts

### *4.2 Transportation of Natural Gas*

Even though most of the gas traded globally, particularly in Europe and North America, is transported via pipelines, LNG is typically transported by sizable tankers with a volume between 25,000 and 160,000 cubic meters. The size of the cargo, the distance travelled, the price of fuel, the cost of insurance, the cost of labour, and the administrative charges all affect how much it costs to transport goods between regions. Additionally, they are influenced by the duration of the contract and are typically higher for short-term agreements. For round-trip distances of 2000 miles, these prices range from $0.19 per MMBTU to $0.14 per MMBTU.

### *4.3 Trade of Natural Gas*

Demand for natural gas and LNG have increased globally due to the growth in gas power generation and liquified natural gas simply serves to supplement pipelines. The demand for natural gas is largely seasonal and is influenced by a variety of variables, including weather, income, demographic trends, and consumer preferences. In 2021, trade of natural gas by pipelines accounted for 49.5 % of total gas traded, figure (5), and the top exporting nations were Russian Federation, Norway, United States, Canada, Turkmenistan, and Algeria. They all exported about 78.9 % of global pipelines export. On the other hand, Europe, United States, Mexico, China, and Canada, were among the top importers of pipelines' gas in 2021, their imports accounted for 82.7% of total imports.

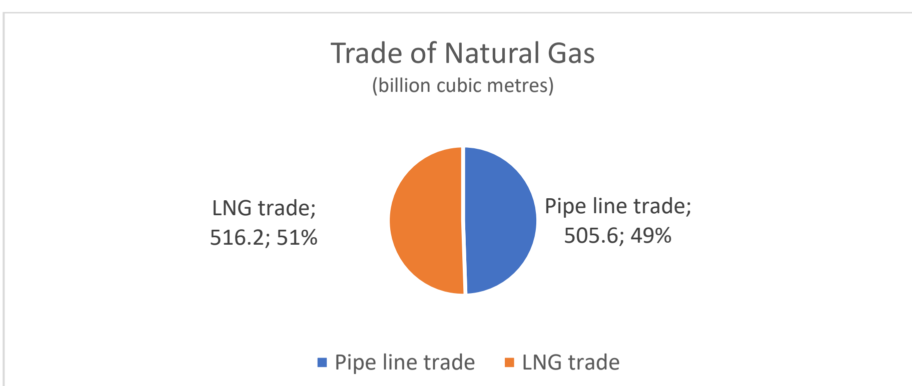


**Fig.5:** Trade of Natural Gas.

The share of LNG's demand on the other side is increasing overtime, while the demand for LNG was 41.3 % of the total gas demanded worldwide in 2011, it increased to 50.5 % in 2021, growing at a rate of 22.3% during the period. The top LNG consumers, in 2021, were China, Europe, Japan, South Korea, India and Taiwan, who together accounted for 85.9 % of all LNG consumed globally figure, (6).

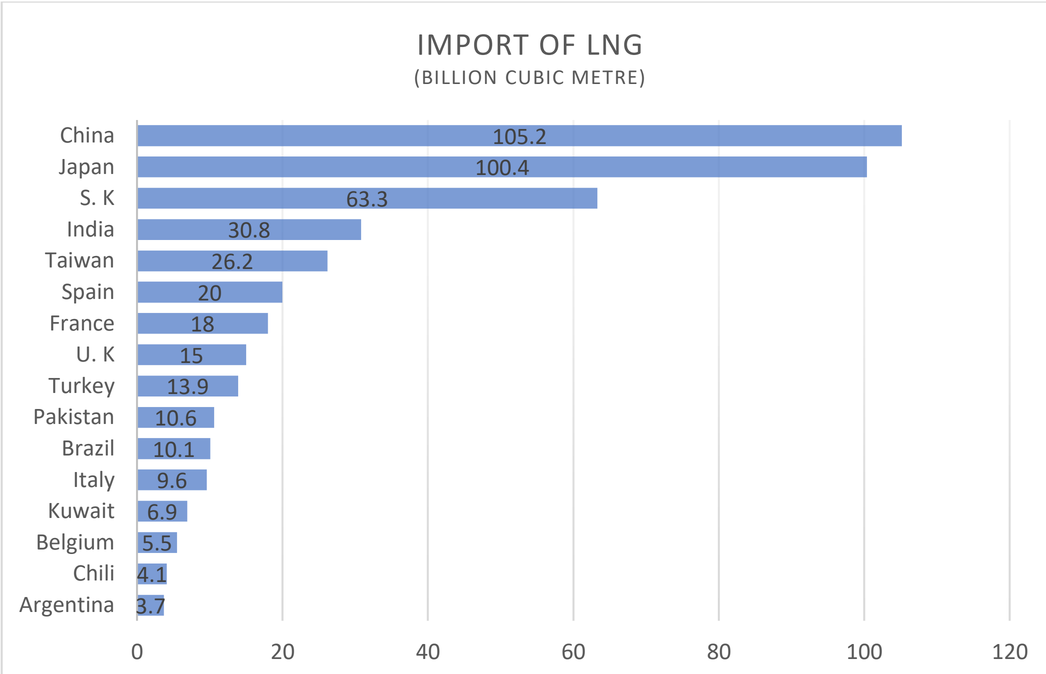


**Fig.6:** Importers of LNG in 2021.

By the same token, the top exporting nations were Australia, Qatar, United States, Russian Federation, Malaysia, and Nigeria. Together, they accounted for 78.7 % of global LNG exports, figure (7).

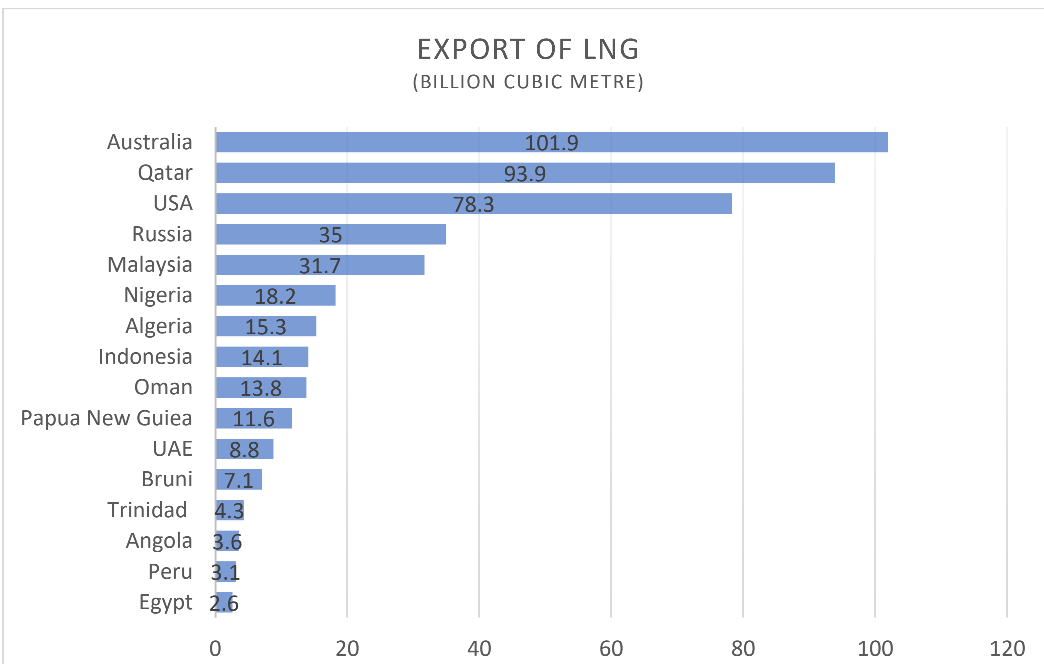


**Fig.7:** Exporters of LNG in 2021.

*Source of Data: bp-stats-review-2022-full-report*

## 5 The Transportation Model

### *5.1 Travel Distances*

The Sea-Distances.org program is used to compute the distances between sources and destinations in nautical miles, which are equal to kilometre, table (1).

**Table 1:** Distances Between Sources & Destinations.

| | Japan | China | S. K | India | Taiwan | Spain | France | Turkey | Pakistan | Italy | Belgium | UK | Brazil | Argentina | Kuwait | Chili |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Qatar | 6512 | 5845 | 6111 | 1300 | 5420 | 4657 | 4414 | 3840 | 870 | 4262 | 6277 | 6626 | 8256 | 8626 | 323 | 13238 |
| Australia | 3919 | 3742 | 4131 | 5918 | 3704 | 10067 | 9824 | 8918 | 6370 | 9672 | 11466 | 11815 | 7304 | 8555 | 7089 | 7304 |
| Malaysia | 2493 | 2069 | 2328 | 2878 | 1645 | 7045 | 6802 | 6228 | 3330 | 6650 | 8665 | 9014 | 9080 | 9501 | 4266 | 10525 |
| United States | 5152 | 5708 | 5230 | 8165 | 5920 | 3147 | 3964 | 6536 | 7978 | 4753 | 4459 | 4310 | 8207 | 8207 | 10844 | 5329 |
| Nigeria | 10637 | 10172 | 10441 | 6863 | 9760 | 3688 | 3931 | 4769 | 7144 | 4720 | 4184 | 4533 | 3397 | 4556 | 7702 | 7165 |
| Russia | 12204 | 11735 | 12001 | 7530 | 11310 | 3086 | 3329 | 4167 | 7343 | 4118 | 1310 | 1229 | 7199 | 8445 | 8461 | 8195 |
| Indonesia | 3035 | 2523 | 2839 | 2708 | 2158 | 6862 | 6619 | 5713 | 3160 | 6467 | 9785 | 10134 | 9644 | 9145 | 5399 | 9098 |
| Trinidad and Tobago | 9161 | 10123 | 9253 | 8370 | 9925 | 3645 | 4169 | 5007 | 8183 | 4958 | 3985 | 4026 | 3268 | 4516 | 8608 | 3304 |
| Oman | 5848 | 5379 | 5645 | 853 | 4954 | 4180 | 3937 | 3031 | 467 | 3785 | 5804 | 6153 | 7783 | 8204 | 691 | 12818 |
| Algeria | 9223 | 8754 | 9020 | 4549 | 8329 | 279 | 406 | 1186 | 4362 | 1139 | 1707 | 2056 | 4732 | 5979 | 4787 | 6901 |
| UAE | 6160 | 5691 | 5957 | 1146 | 5266 | 4503 | 4260 | 3354 | 716 | 4108 | 6123 | 6472 | 8070 | 8491 | 445 | 13103 |
| Egypt | 7876 | 7407 | 7673 | 3202 | 6982 | 1473 | 1238 | 375 | 3015 | 1090 | 3431 | 3709 | 6385 | 7632 | 3137 | 14255 |

*Source: Data generated by the author using the Sea-Distances.org program measured in nautical miles.*

### *5.2 Transportation Cost*

According to the LNG freight cost calculator made available by Capra Energy Group, the transportation costs between sources and destinations for our model are approximations. These expenses are calculated using a tanker with a 160,000 m3 LNG capacity, an average speed, the overall distance travelled, canal tolls, port fees, heel and boiloff gas, table (2).

**Table 2:** LNG Total Freight Cost ($/MMBtu).

| | Japan | China | S. K | India | Taiwan | Spain | France | Turkey | Pakistan | Italy | Belgium | Greece | Portugal | U. K | Brazil | Argentina | Kuwait | Chili | Total Supply |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Qatar | 4.93 | 4.04 | 4.64 | 0.88 | 4.04 | 4.55 | 3.46 | 3.12 | 1.03 | 3.69 | 4.87 | 3.08 | 4.27 | 4.89 | 6.15 | 6.15 | 0.6 | 10.34 | **93.9** |
| Australia | 2.91 | 2.91 | 3.49 | 4.64 | 2.91 | 8.9 | 7.66 | 7.04 | 5.1 | 7.65 | 9.25 | 7 | 8.27 | 8.94 | 6.48 | 6.48 | 3.8 | 5.32 | **101.9** |
| Malaysia | 2.04 | 2.4 | 1.76 | 2.58 | 2.4 | 6.69 | 5.8 | 4.9 | 3.03 | 5.48 | 7.02 | 4.86 | 6.08 | 6.73 | 7.09 | 7.09 | 3.5 | 7.78 | **31.7** |
| USA | 7.3 | 7.93 | 8.24 | 6.38 | 7.93 | 2.58 | 3.19 | 4.06 | 6.54 | 4.05 | 2.89 | 3.73 | 2.59 | 2.62 | 3.19 | 3.19 | 6.74 | 3.45 | **78.3** |
| Nigeria | 8.17 | 7.23 | 7.86 | 5.36 | 7.23 | 3.29 | 3.32 | 3.91 | 5.52 | 3.89 | 3.61 | 3.87 | 2.73 | 3.33 | 2.46 | 2.46 | 5.72 | 5.75 | **18.2** |
| Russia | 0.88 | 1.16 | 0.89 | 4.3 | 1.16 | 8.21 | 7.3 | 6.68 | 4.46 | 7.29 | 8.88 | 6.64 | 7.91 | 8.57 | 8.85 | 8.85 | 5.25 | 7.11 | **35** |
| Indonesia | 2.01 | 1.45 | 2.01 | 2.84 | 1.45 | 6.97 | 6.08 | 5.17 | 3.29 | 5.52 | 7.3 | 5.13 | 6.36 | 7.01 | 7.07 | 7.07 | 3.77 | 7.34 | **14.1** |
| Trinidad | 6.95 | 7.58 | 7.58 | 6.34 | 7.58 | 2.84 | 3.15 | 3.74 | 6.5 | 3.72 | 3.15 | 3.69 | 2.56 | 2.87 | 2.01 | 2.01 | 6.7 | 2.84 | **4.3** |
| Oman | 4.63 | 3.45 | 4.34 | 0.6 | 3.45 | 4.25 | 3.41 | 2.83 | 0.75 | 3.39 | 4.57 | 2.79 | 3.97 | 4.59 | 5.84 | 5.84 | 0.92 | 9.68 | **13.8** |
| Algeria | 7.63 | 6.39 | 7.33 | 3.68 | 6.39 | 1.16 | 0.64 | 1.19 | 3.84 | 1.18 | 1.47 | 1.15 | 0.62 | 1.2 | 2.89 | 2.89 | 4.03 | 5.51 | **15.3** |
| UAE | 4.92 | 3.74 | 4.63 | 0.86 | 3.74 | 4.54 | 3.69 | 3.11 | 1.02 | 3.68 | 4.86 | 3.07 | 4.26 | 4.88 | 6.14 | 6.14 | 0.6 | 10 | **8.8** |
| Egypt | 6.4 | 5.19 | 6.1 | 2.54 | 5.19 | 2.02 | 1.21 | 0.65 | 2.7 | 1.19 | 2.61 | 0.61 | 1.75 | 2.34 | 4.07 | 4.07 | 2.88 | 6.43 | **2.6** |
| Bruni | 2.03 | 1.18 | 1.75 | 2.57 | 1.18 | 6.67 | 5.79 | 4.89 | 3.02 | 5.47 | 7.01 | 4.85 | 6.07 | 6.71 | 7.08 | 7.08 | 3.49 | 7.77 | **7.1** |
| Angola | 7.66 | 6.42 | 7.35 | 4.88 | 6.42 | 3.4 | 3.43 | 4.02 | 5.03 | 4 | 3.72 | 3.97 | 2.83 | 3.44 | 2.28 | 2.28 | 5.23 | 5.26 | **3.6** |
| Papua New Guiea | 2.62 | 2.34 | 2.92 | 4.05 | 2.34 | 8.27 | 7.35 | 6.43 | 4.51 | 7.03 | 8.61 | 6.38 | 7.65 | 8.31 | 7.42 | 7.42 | 5 | 5.93 | **11.6** |
| Peru | 0.98 | 7.41 | 7.1 | 9.62 | 7.41 | 4.84 | 4.88 | 5.77 | 9.79 | 5.76 | 4.87 | 5.73 | 4.56 | 4.88 | 3.98 | 3.98 | 16.67 | 0.98 | **3.1** |
| Total Demand | 100.4 | **105.2** | **63.3** | **30.8** | **26.2** | **20** | **18** | **13.9** | **10.6** | **9.6** | **5.5** | **0** | **0** | **15** | **10.1** | **3.7** | **6.9** | **4.1** | 443.3 |

*Source: Data generated by the author.*

## *5.3 Delivered Quantities from Sources to Destinations*

In billion cubic meters, table (3) displays the actual amounts of Liquefied Natural Gas (LNG) transported in 2021 between the 16 sources and the 16 destinations around the globe. The total transportation expenses are estimated to be **$1,576.96** per MMBtu calculated based on the LNG freight cost calculator offered by Capra Energy Group.

**Table 3:** Quantities of LNG Delivered from Source to Destination.

| | Japan | China | S. K | India | Taiwan | Spain | France | Turkey | Pakistan | Italy | Belgium | U. K | Brazil | Argentina | Kuwait | Chili | otal Suppl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Qatar | 12.3 | 12.3 | 16.1 | 13.6 | 6.5 | 2.4 | 0.7 | 0.3 | 8.1 | 6.5 | 3.2 | 6 | 0.9 | 1.4 | 3.6 | | **93.9** |
| Australia | 36.3 | 43.6 | 12.9 | 0.4 | 8.6 | 0.1 | | | | | | | | | | | **101.9** |
| Malaysia | 13.9 | 11.7 | 5.3 | 0.1 | 0.7 | | | | | | | | | | | | **31.7** |
| USA | 9.6 | 12.4 | 12.1 | 5.6 | 2.4 | 5.8 | 4.3 | 4.5 | 1.2 | 1 | 0.2 | 4 | 8.7 | 2.2 | 0.9 | 3.4 | **78.3** |
| Nigeria | 1.2 | 2.1 | 0.9 | 2 | 0.8 | 4.3 | 3.5 | 1.5 | 0.2 | 0.3 | | | 0.1 | | 1.3 | | **18.2** |
| Russia | 8.8 | 6.2 | 3.9 | 0.6 | 2.6 | 3.3 | 4.7 | | | | 1.9 | 3 | | | | | **35** |
| Indonesia | 2.6 | 6.6 | 3.3 | | 1.6 | | | | | | | | | | | | **14.1** |
| Trinidad | | 0.6 | 0.1 | 0.4 | 0.2 | 1.1 | | 0.2 | | 0.2 | | 0.2 | 0.3 | 0.1 | 0.2 | 0.7 | **4.3** |
| Oman | 2.6 | 2.2 | 6.3 | 1.7 | 0.6 | | | | | | | | | | 0.4 | | **13.8** |
| Algeria | | 0.3 | | 0.1 | | 2.1 | 4.5 | 6.1 | | 1.3 | 0.1 | 0.7 | | | 0.1 | | **15.3** |
| UAE | 1.8 | 1 | 0.4 | 4.9 | 0.1 | | | | 0.3 | | | | | | 0.3 | | **8.8** |
| Egypt | | | | | | 0.4 | 0.2 | 1.3 | | 0.3 | 0.1 | 0.3 | | | | | **2.6** |
| Bruni | 5.8 | 0.9 | 0.3 | | 0.1 | | | | | | | | | | | | **7.1** |
| Angola | | 0.6 | 0.2 | 1.4 | | 0.4 | | | 0.8 | | | | 0.1 | | 0.1 | | **3.6** |
| ua New Gu | 4.8 | 4.5 | 0.3 | | 2 | | | | | | | | | | | | **11.6** |
| Peru | 0.7 | 0.2 | 1.2 | | | 0.1 | 0.1 | | | | | 0.8 | | | | | **3.1** |
| **otal Demar** | **100.4** | **105.2** | **63.3** | **30.8** | **26.2** | **20** | **18** | **13.9** | **10.6** | **9.6** | **5.5** | **15** | **10.1** | **3.7** | **6.9** | **4.1** | 443.3 |

*Source: bp-stats-review-2022-full-report*

The actual quantities of LNG traded between suppliers and consumers for each country separately, together with the transportation costs, are shown in Tables (3-a), (3-b), and (3-c) below.

Table: (3-a)

Actual Quantities of LNG Traded for Countries in America with the Transportation Costs

| | **Brazil** | | **Argentina** | | **Chili** | |
|---|---|---|---|---|---|---|
| | **LNG** | **Cost** | **LNG** | **Cost** | **LNG** | **Cost** |
| Qatar | 0.9 | 5.535 | 1.4 | 8.61 | | 0 |
| Australia | | 0 | | 0 | | 0 |
| Malaysia | | 0 | | 0 | | 0 |
| USA | 8.7 | 27.753 | 2.2 | 7.018 | 3.4 | 11.73 |
| Nigeria | 0.1 | 0.246 | | 0 | | 0 |
| Russia | | 0 | | 0 | | 0 |
| Indonesia | | 0 | | 0 | | 0 |
| Trinidad | 0.3 | 0.603 | 0.1 | 0.201 | 0.7 | 1.988 |
| Oman | | 0 | | 0 | | 0 |
| Algeria | | 0 | | 0 | | 0 |
| UAE | | 0 | | 0 | | 0 |
| Egypt | | 0 | | 0 | | 0 |
| Bruni | | 0 | | 0 | | 0 |
| Angola | 0.1 | 0.228 | | 0 | | 0 |
| Papua New Guinea | | 0 | | 0 | | 0 |
| Peru | | 0 | | 0 | | 0 |
| **Total Demand** | **10.1** | | **3.7** | | **4.1** | |
| **Total Transportation Cost** | | **34.365** | | **15.829** | | **13.718** |

Table: (3-b)

Actual Quantities of LNG Traded for Countries in Europe with the Transportation Costs

| | Spain | | France | | Turkey | | Italy | | Belgium | | U. K | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LNG | Cost | LNG | Cost | LNG | Cost | LNG | Cost | LNG | Cost | LNG | Cost |
| Qatar | 2.4 | 10.92 | 0.7 | 2.422 | 0.3 | 0.936 | 6.5 | 23.985 | 3.2 | 15.584 | 6 | 29.34 |
| Australia | 0.1 | 0.89 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Malaysia | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| USA | 5.8 | 14.964 | 4.3 | 13.717 | 4.5 | 18.27 | 1 | 4.05 | 0.2 | 0.578 | 4 | 10.48 |
| Nigeria | 4.3 | 14.147 | 3.5 | 11.62 | 1.5 | 5.865 | 0.3 | 1.167 | | 0 | | 0 |
| Russia | 3.3 | 27.093 | 4.7 | 34.31 | | 0 | | 0 | 1.9 | 16.872 | 3 | 25.71 |
| Indonesia | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Trinidad | 1.1 | 3.124 | | 0 | 0.2 | 0.748 | 0.2 | 0.744 | | 0 | 0.2 | 0.574 |
| Oman | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Algeria | 2.1 | 2.436 | 4.5 | 2.88 | 6.1 | 7.259 | 1.3 | 1.534 | 0.1 | 0.147 | 0.7 | 0.84 |
| UAE | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Egypt | 0.4 | 0.808 | 0.2 | 0.242 | 1.3 | 0.845 | 0.3 | 0.357 | 0.1 | 0.261 | 0.3 | 0.702 |
| Bruni | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Angola | 0.4 | 1.36 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Papua New Guinea | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Peru | 0.1 | 0.484 | 0.1 | 0.488 | | 0 | | 0 | | 0 | 0.8 | 3.904 |
| **Total Demand** | **20** | | **18** | | **13.9** | | **9.6** | | **5.5** | | **15** | |
| **Total Transportation Cost** | | **76.226** | | **65.679** | | **33.923** | | **31.837** | | **33.442** | | **71.55** |

Table: (3-c)

Actual Quantities of LNG Traded for Countries in Asia with the Transportation Costs

| | Japan | | China | | S. K | | India | | Taiwan | | Pakistan | | Kuwait | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LNG | Cost | LNG | Cost | LNG | Cost | LNG | Cost | LNG | Cost | LNG | Cost | LNG | Cost |
| Qatar | 12.3 | 60.639 | 12.3 | 49.692 | 16.1 | 74.704 | 13.6 | 11.968 | 6.5 | 26.26 | 8.1 | 8.343 | 3.6 | 2.16 |
| Australia | 36.3 | 105.633 | 43.6 | 126.876 | 12.9 | 45.021 | 0.4 | 1.856 | 8.6 | 25.026 | | 0 | | 0 |
| Malaysia | 13.9 | 28.356 | 11.7 | 28.08 | 5.3 | 9.328 | 0.1 | 0.258 | 0.7 | 1.68 | | 0 | | 0 |
| USA | 9.6 | 70.08 | 12.4 | 98.332 | 12.1 | 99.704 | 5.6 | 35.728 | 2.4 | 19.032 | 1.2 | 7.848 | 0.9 | 6.066 |
| Nigeria | 1.2 | 9.804 | 2.1 | 15.183 | 0.9 | 7.074 | 2 | 10.72 | 0.8 | 5.784 | 0.2 | 1.104 | 1.3 | 7.436 |
| Russia | 8.8 | 7.744 | 6.2 | 7.192 | 3.9 | 3.471 | 0.6 | 2.58 | 2.6 | 3.016 | | 0 | | 0 |
| Indonesia | 2.6 | 5.226 | 6.6 | 9.57 | 3.3 | 6.633 | | 0 | 1.6 | 2.32 | | 0 | | 0 |
| Trinidad | | 0 | 0.6 | 4.548 | 0.1 | 0.758 | 0.4 | 2.536 | 0.2 | 1.516 | | 0 | 0.2 | 1.34 |
| Oman | 2.6 | 12.038 | 2.2 | 7.59 | 6.3 | 27.342 | 1.7 | 1.02 | 0.6 | 2.07 | | 0 | 0.4 | 0.368 |
| Algeria | | 0 | 0.3 | 1.917 | | 0 | 0.1 | 0.368 | | 0 | | 0 | 0.1 | 0.403 |
| UAE | 1.8 | 8.856 | 1 | 3.74 | 0.4 | 1.852 | 4.9 | 4.214 | 0.1 | 0.374 | 0.3 | 0.306 | 0.3 | 0.18 |
| Egypt | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Bruni | 5.8 | 11.774 | 0.9 | 1.062 | 0.3 | 0.525 | | 0 | 0.1 | 0.118 | | 0 | | 0 |
| Angola | | 0 | 0.6 | 3.852 | 0.2 | 1.47 | 1.4 | 6.832 | | 0 | 0.8 | 4.024 | 0.1 | 0.523 |
| Papua New Guinea | 4.8 | 12.576 | 4.5 | 10.53 | 0.3 | 0.876 | | 0 | 2 | 4.68 | | 0 | | 0 |
| Peru | 0.7 | 0.686 | 0.2 | 1.482 | 1.2 | 8.52 | | 0 | | 0 | | 0 | | 0 |
| **Total Demand** | **100.4** | | **105.2** | | **63.3** | | **30.8** | | **26.2** | | **10.6** | | **6.9** | |
| **Total Transportation Cost** | | **333.412** | | **369.646** | | **287.278** | | **78.08** | | **91.87** | | **21.63** | | **18.476** |

## 6 Discussions of Findings

This study employed the North-West corner model to identify the shipping path that will lower the cost of transporting Liquefied Natural Gas (LNG) between 16 sources and 16 destinations around the globe. Table (4) demonstrates that, with a minimum total transportation cost of **$1,161.22** per MMBtu, the North-West corner model offered the best source for each destination. The optimal resource distribution between suppliers and consumers for each country separately with the lowest transportation costs is shown in Tables (4-a), (4-b), and (4-c) below.

**Table 4:** North-West Model & the Least Transportation Cost.

| Optimal cost = $1,161.22 | Japan | China | S. K | India | Taiwan | Spain | France | Turkey | Pakistan | Italy | Belgium | U. K | Brazil | Argentina | Kuwait | Chili |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Qatar | | 19.4 | | 30.8 | 26.2 | | | | 10.6 | | | | | | 6.9 | |
| Australia | 75.1 | 26.8 | | | | | | | | | | | | | | |
| Malaysia | | | 31.7 | | | | | | | | | | | | | |
| USA | 18.8 | | | | | 20 | 18 | 1 | | | 5.5 | 15 | | | | |
| Nigeria | | | | | | | | | | 4.6 | | | 9.9 | 3.7 | | |
| Russia | 3.4 | | 31.6 | | | | | | | | | | | | | |
| Indonesia | | 14.1 | | | | | | | | | | | | | | |
| Trinidad | | | | | | | | | | | | | 0.2 | | | 4.1 |
| Oman | | 13.8 | | | | | | | | | | | | | | |
| Algeria | | | | | | | | 10.3 | | 5 | | | | | | |
| UAE | | 8.8 | | | | | | | | | | | | | | |
| Egypt | | | | | | | | 2.6 | | | | | | | | |
| Bruni | | 7.1 | | | | | | | | | | | | | | |
| Angola | | 3.6 | | | | | | | | | | | | | | |
| Papua New Guiea | | 11.6 | | | | | | | | | | | | | | |
| Peru | 3.1 | | | | | | | | | | | | | | | |

*The data on the table generated by the model as the optimal solution with the minimum transportation costs.*

Table: (4-a)

Actual Quantities of LNG Traded for Countries in America with the Least Transportation Costs Model

| | Brazil | | Argentina | | Chili | |
|---|---|---|---|---|---|---|
| | LNG | Cost | LNG | Cost | LNG | Cost |
| Qatar | | 0 | | 0 | | 0 |
| Australia | | 0 | | 0 | | 0 |
| Malaysia | | 0 | | 0 | | 0 |
| USA | | 0 | | 0 | | 0 |
| Nigeria | 9.9 | 24.354 | 3.7 | 9.102 | | 0 |
| Russia | | 0 | | 0 | | 0 |
| Indonesia | | 0 | | 0 | | 0 |
| Trinidad | 0.2 | 0.402 | | 0 | 4.1 | 11.644 |
| Oman | | 0 | | 0 | | 0 |
| Algeria | | 0 | | 0 | | 0 |
| UAE | | 0 | | 0 | | 0 |
| Egypt | | 0 | | 0 | | 0 |
| Bruni | | 0 | | 0 | | 0 |
| Angola | | 0 | | 0 | | 0 |
| Papua New Guinea | | 0 | | 0 | | 0 |
| Peru | | 0 | | 0 | | 0 |
| **Total Demand** | **10.1** | | **3.7** | | **4.1** | |
| **Total Transportation Cost** | | **24.756** | | **9.102** | | **11.644** |

Table: (3-b)

Actual Quantities of LNG Traded for Countries in Europe with the Least Transportation Costs Model

| | Spain | | France | | Turkey | | Italy | | Belgium | | U. K | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LNG | Cost | LNG | Cost | LNG | Cost | LNG | Cost | LNG | Cost | LNG | Cost |
| Qatar | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Australia | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Malaysia | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| USA | 20 | 51.6 | 18 | 57.42 | 1 | 4.06 | | 0 | 5.5 | 15.895 | 15 | 39.3 |
| Nigeria | | 0 | | 0 | | 0 | 4.6 | 17.894 | | 0 | | 0 |
| Russia | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Indonesia | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Trinidad | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Oman | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Algeria | | 0 | | 0 | 10.3 | 12.257 | 5 | 5.9 | | 0 | | 0 |
| UAE | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Egypt | | 0 | | 0 | 2.6 | 1.69 | | 0 | | 0 | | 0 |
| Bruni | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Angola | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| pua New Guiea | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Peru | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| **'otal Deman** | **20** | | **18** | | **13.9** | | **9.6** | | **5.5** | | **15** | |
| **'otal Transportation Cos** | | **51.6** | | **57.42** | | **18.007** | | **23.794** | | **15.895** | | **39.3** |

Table: (4-c)

Actual Quantities of LNG Traded for Countries in Asia with the Least Transportation Costs Model

| | Japan | | China | | S. K | | India | | Taiwan | | Pakistan | | Kuwait | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LNG | Cost | LNG | Cost | LNG | Cost | LNG | Cost | LNG | Cost | LNG | Cost | LNG | Cost |
| Qatar | | 0 | 19.4 | 78.376 | | 0 | 30.8 | 27.104 | 26.2 | 105.848 | 10.6 | 10.918 | 6.9 | 4.14 |
| Australia | 75.1 | 218.541 | 26.8 | 77.988 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Malaysia | | 0 | | 0 | 31.7 | 55.792 | | 0 | | 0 | | 0 | | 0 |
| USA | 18.8 | 137.24 | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Nigeria | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Russia | 3.4 | 2.992 | | 0 | 31.6 | 28.124 | | 0 | | 0 | | 0 | | 0 |
| Indonesia | | 0 | 14.1 | 20.445 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Trinidad | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Oman | | 0 | 13.8 | 47.61 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Algeria | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| UAE | | 0 | 8.8 | 32.912 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Egypt | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Bruni | | 0 | 7.1 | 8.378 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Angola | | 0 | 3.6 | 23.112 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Papua New Guiea | | 0 | 11.6 | 27.144 | | 0 | | 0 | | 0 | | 0 | | 0 |
| Peru | 3.1 | 3.038 | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 |
| **Total Demand** | **100.4** | | **105.2** | | **63.3** | | **30.8** | | **26.2** | | **10.6** | | **6.9** | |
| **Total Transportation Cost** | | **361.811** | | **315.965** | | **83.916** | | **27.104** | | **105.848** | | **10.918** | | **4.14** |

## 7 Conclusions

The study has used the North-West Corner Method approach to investigate the possibility of finding the optimal solution to the problem of finding new sources to fulfil demand requirements for LNG with minimum transportation costs. Our result show that the model is reliable for implementation since it gave a lower transportation cost compared to the actual. The total transportation costs obtained by the model is **$1,161.22** per MMBtu, to deliver Liquefied Natural Gas (LNG) from sources to destinations. This amount is reduced by $415.74 per MMBtu compared with the estimated actual cost of **$1,576.96** per MMBtu, a reduction of (-26.36%). It is concluded that, if concern countries apply the solution reached by our model, they will enjoy securing new locations, lower delivery cost with less distances, and quicker time to meet their gas requirements.

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