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GLOBAL NATURAL GAS DEMAND PROJECTIONS UNDER FUZZY LOGIC

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Abstract

Being the cleanest burning fossil fuel, natural gas provides a number of environmental benefits compared to other fossil fuels, particularly in terms of air quality and greenhouse gas emissions. Therefore, it contributes for almost one-third of total global energy demand growth through the last decade, and that fastest growing fossil fuel more than any other fuel source. Due to Covid pandemic, global natural gas consumption has fallen in 2020 in major markets even, i.e. declined by approx. 4% in 2020 and reached 3.840 bcm. In the study interviews with energy experts/managers are performed and fuzzy multi objective mathematical model (by using fuzzy AHP, fuzzy TOPSIS and fuzzy VIKOR) is developed to calculate World's natural gas demand under high and low demand scenarios. By the help of model, the usage of natural gas amount in World by regions between 2020 and 2040 is calculated. In Scenario-High it will increase by approx. 47 % between 2020 and 2040 and reached 5.650 bcm in 2040. In Scenario-Low it will increase by approx. 18,5 % from 2020 to 2040 and reached 4.550 bcm in 2040. It is the only fossil fuel expected to grow beyond 2030 since it is clean energy source. In Scenario-High natural gas demand by region is calculated/projected as follows: in 2030 North America 1250 bcm, Central and South America 250 bcm, Europe 650 bcm, Middle East 750 bcm, Eurasia 650 bcm, Asia Pacific 1250 bcm. And in 2040 it is calculated as follows: North America 1350 bcm, Central and South America 300 bcm, Europe 650 bcm, Middle East 920 bcm, Eurasia 680 bcm, Asia Pacific 1750 bcm. The study shows that EU's, US's and Word's decarbonizing energy aim, i.e. curbing the emissions trajectory to net zero, by 2050 is nearly impossible. EU's and some US states' goal to reach zero carbon emissions by 2050 is postponed.

Keywords:

Natural Gas Demand, Energy, Fuzzy Logic, Fuzzy AHP/Fuzzy TOPSIS/Fuzzy VIKOR, World.

1. Introduction

Natural gas is the cleanest burning and fastest growing fossil fuel, contributing for almost one-third of total energy demand growth through the last decade, more than any other fuel. Being the cleanest burning fossil fuel, natural gas provides a number of environmental benefits compared to other fossil fuels, particularly in terms of air quality and greenhouse gas emissions.

Its storability and the operational flexibility of gas-fired power plants, allows natural gas to respond to both seasonal and short-term demand fluctuations and to enhance electricity supply security in power systems with a growing share of variable renewables.

By the availability of shale gas and the rising supplies of flexible LNG demand, natural gas market becomes more global commodity. As the usage/trade of natural gas increases, the interconnectivity of gas markets that create new facets and dimensions of natural gas security increases.

Natural gas is an essential energy resource not only in homes but also in industrial sector; natural gas is an essential raw material for many common products, i.e. paints, fertilizers, plastics, antifreeze, and medicine. Today fossil fuels, i.e. coal, oil, and natural gas, are still widely used in the World's energy sector. Today, approximately 24 percent of the energy consumption of the US comes from natural gas.

Energy management problems are solved by multiple objective optimization methods, i.e. MOP methods. Multiple objective optimization in engineering is often very challenging to solve, necessitating sophisticated techniques to tackle. Multiple objective optimization considers optimization problems involving more than one objective function to be optimized simultaneously. Multiple objective optimization is typically suitable in such problems where decisions regarding optimal solutions are taken by consideration of the trade-offs between the conflicting objectives. Past studies in literature using multiple objective programming model (Wang, 2009, 2018, Deshmukh, S.S., 2009, Lee et al., 2010, Ho et al., 2018, Enea, 2018, Chen et al., 2015, Cayir et al., 2018, Pokharel, Chandrashekara, 1998, Incekara, 2017, Iniyana, 2006, Borges, Antunes, 2003, Chang, 1996, Gu, 2006, Saaty, 2012, Mangla, 2015, Satrovic, 2018, Chen, et al., 2001, Incekara, 2013, Incekara, 2017, Incekara, 2018, Incekara, 2019, Incekara, 2020) were performed for energy investment/expansion plans of regions/countries.

2. World's Natural Gas Sector

Fossil fuels still play an important role in World's energy mix, with natural gas being the most significant. Since 2010, 80% of growth has been concentrated in three key regions: US where the shale gas revolution is in full swing; China where economic expansion and air quality concerns have underpinned rapid growth; and the Middle East where natural gas is a gateway to economic diversification from oil.

In 2018 natural gas demand by region is as follows: North America 1067 bcm, Central and South America 169 bcm, Europe 617 bcm, Middle East 539 bcm, Eurasia 598 bcm, Asia Pacific 815 bcm. The world's natural gas demand is estimated to fall in 2020 down to 3,840 billion cubic meters (bcm) whereas in 2018 it is 3,805 billion cubic meters (bcm).

Natural gas had a remarkable year in 2018, with a 4.6% increase in consumption accounting for nearly half of the increase in global energy demand. Due to Covid pandemic, global natural gas consumption has fallen in 2020 in major markets even. Natural gas demand declined by 3%. LNG demand was more resilient and managed to grow 1%. Natural gas will be the strongest-growing fossil fuel.

The world's natural gas demand is decreased in 2020 down to 3,840 billion cubic meters (bcm). Natural gas demand did not decline as much as oil demand, as low prices made gas competitive in the power sector and shielded the share of gas demand from falling further. While demand in Asia remained relatively strong, European consumption was more severely affected, dropping around 7%, i.e. by approx. 40 bcm, followed by Africa with 26 bcm. The COVID pandemic impacted North America the most as a gas-producing region with production estimated to have dropped by approx. 47 bcm from 2019 to 1,103 bcm in 2020.

Global LNG liquefaction capacity grew by 5% in 2020, reaching 464 million tons per annum, as new plants, mainly in US, started operations. And it is approx. 12% of World natural gas demand. The estimated capacity in US will reach 71 million tons per annum with a 42% increase whereas in Russia's liquefaction capacity has reached 29 million tons per annum.

Despite COVID lockdowns, global liquefied natural gas (LNG) imports grew 3% to 363 million tons in 2020. China mainly led the increase in Asian LNG demand at 4% year-on-year.

IEA predicted/forecasted global natural gas production is expected to grow by approx. 27% to 4,860 bcm in 2040 with most additions coming from North America due to increase in LNG liquefaction plants. And Asia Pasific is estimated to make the largest addition to the natural gas demand growth compared to other regions of the World. And IEA predicted/forecasted that global LNG liquefaction capacity will increase. LNG demand is expected to grow 3.4 % per annum until 2035; it means that approx. 150 million metric tons of additional capacity is required to meet demand growth in 2030. LNG demand growth will slow markedly but will still grow by 0.5 % from 2035 to 2050, it means that more than 250 million metric tons of new capacity is required by 2040.

3. Fuzzy Multi Criteria Decision Making Methods (FMCDM)

In the study; an integrated Fuzzy AHP- Fuzzy TOPSIS- Fuzzy VIKOR approaches are used to assess/evaluate World's natural gas sector.

In literature Fuzzy Multi Criteria Decision Making Methods (FMCDM) are used in different fields by many researchers and Fuzzy AHP, Fuzzy TOPSIS & Fuzzy VIKOR are also used in many sectors, i.e. to select best renewable energy resource of World, to select best project (Enea and Piazza, 2004), performance evaluation of national R&D companies (Deshmukh, 2009), to evaluate intelligent timetable (Isaai et al., 2011), to evaluate the criteria for human resource for science and technology (Chen et al., 2015), for analyzing customer preferences (Kumar, 2015), to evaluate risk analysis in green supply chain (Mangla et al., 2015), and to select machine tools (Nguyen et al., 2015).

In the study triangular fuzzy numbers were employed in order to enhance the degree of judgment and bring flexibility in decision-making. DMs specified their preferences by using linguistic variables. Figure 1 shows the flow chart of this study and decision-making procedure for energy systems selection. The determination of weights was carried out as follows:

(1) modelling the problem by containing the goals,

(2) calculating the weights of criteria by judging the pairwise comparisons,

(3) analyzing the outcomes by judging the overall priorities for the hierarchy,

(4) final decision.

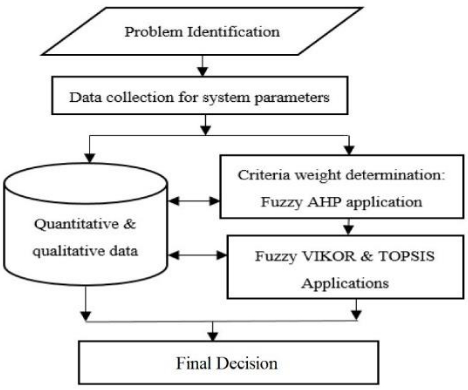

Figure 1. Flow chart for the final decision procedure

3.1. Fuzzy AHP Method

Since the standard AHP method does not include the possibility of situations with ambiguity in the estimation, it is possible to upgrade this method with fuzzy approach. This approach is called the Fuzzy AHP method. Instead of one defined value, in the Fuzzy AHP method full range of values that include unsafe attitudes of decision maker should be generated. For that process it is possible to use triangular fuzzy numbers, trapezoidal or Gaussian fuzzy numbers. The Fuzzy AHP method suggests their application directly in criteria pairs comparison matrix. Triangular fuzzy numbers are used in most cases/problems by many researchers in literature because of this reason in the study triangular fuzzy numbers method is used in Fuzzy AHP method. A triangular fuzzy number that is defined in R set can be described as Ñ= (l, n, u) where l is the minimum, n is the most possible and u is the maximum value of a fuzzy case. Its triangular membership function is characterized below (Deng, 1999) which is presented in Figure 2 and in equation (1).

$$\mu\tilde{N}(x) = \begin{cases} (x-l)/(n-l), & l \leq x \leq n \\ (x-u)/(n-u), & n \leq x \leq u \\ 0, & x < l \text{ or } x > u \end{cases} \tag{1}$$

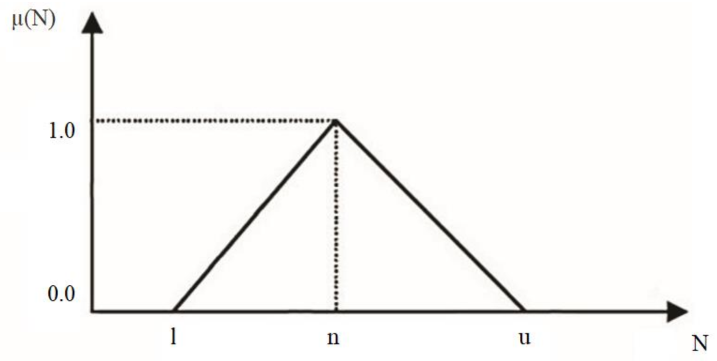

Figure 2. Triangular fuzzy number

Triangular fuzzy number Ñ (shown in Figure 2) can be described as an interval of real numbers where each of them has a degree of belonging to the interval between 0 and 1. Triangular fuzzy number is defined with three real numbers, expressed as l, n and u. In the study the performance of each scenario to each criterion is introduced as a fuzzy number. And in the study the ratings of qualitative criteria are considered as linguistic variables. These linguistic variables can be expressed in positive triangular fuzzy numbers as described in Table 1.

Table 1. Linguistic Variables for the Alternatives

Linguistic Terms-Abbreviation	**Linguistic Variables**	**Triangular Fuzzy Numbers**
SDA	Strongly Disagree	(0, 0, 0.15)
DA	Disagree	(0.15, 0.15, 0.15)
LDA	Little Disagree	(0.30, 0.15, 0.20)
NC	No Comment	(0.50, 0.20, 0.15)

LA	Little Agree	(0.65, 0.15, 0.15)
A	Agree	(0.80, 0.15, 0.20)
SA	Strongly Agree	(1, 0.20, 0)

After forming a matrix of fuzzy criteria comparison it should be defined vector of criteria weights W. For that purpose, the following equations/steps were used in the study.

Let X ={x1, x2,..., xm } be an object set, and G={g1, g2,...,gn} be a goal set. N extent analysis values for each object can be obtained as $N_{gi}^{1}, N_{gi}^{2}, \ldots, N_{gi}^{n}$ i= 1,2,…n

Step 1: The values of fuzzy extensions for the i-th object are given in Expression (2);

$$Si = \sum_{j=1}^{n} N_{gi}^{j} \otimes \left[\sum_{i=1}^{m}\sum_{j=1}^{n} N_{gi}^{j}\right]^{-1} \quad (2)$$

In order to obtain the expression $\left[\sum_{i=1}^{m}\sum_{j=1}^{n} N_{gi}^{j}\right]$ it is necessary to perform additional fuzzy operations with n values of the extent analysis, which is represented in Equation (3) and (4);

$$\sum_{j=1}^{n} N_{gi}^{j} = \left(\sum_{j=1}^{n} lj, \sum_{j=1}^{n} nj, \sum_{j=1}^{n} uj\right) \quad (3)$$

$$\left[\sum_{i=1}^{m}\sum_{j=1}^{n} N_{gi}^{j}\right] = \left(\sum_{i=1}^{m} li, \sum_{i=1}^{m} ni, \sum_{i=1}^{m} ui\right) \quad (4)$$

And it is required to calculate the inverse vector above by using Expression (5);

$$\left[\sum_{i=1}^{m}\sum_{j=1}^{n} N_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{m} ui}, \frac{1}{\sum_{i=1}^{m} ni}, \frac{1}{\sum_{i=1}^{m} li}\right) \quad (5)$$

Step 2: While N_1 and N_2 are triangular fuzzy numbers, the degree of possibility for $N_2 \geq N_1$ is defined as:

$$V(N_2 \geq N_1) = \sup_{y \geq x} \left(\min(\mu N_1(x), \mu N_2(y))\right) \quad (6)$$

It can be represented in the following manner by Expression (7):

$$V(N_2 \geq N_1) = hgt(N_2 \cap N_1)\ \mu N_2(d) \quad (7)$$

$$= \begin{cases} 1, & \text{if } n_2 \geq n_1 \\ 0, & \text{if } l_1 \geq l_2 \\ \frac{(l_1 - u_2)}{(n_2 - u_2)(m_1 - l_1)}, & \text{otherwise} \end{cases} \quad (8)$$

Where d is the ordinate of the highest intersection point D between μN_1 and μN_2.

To compare μN_1 and μN_2, values of both, $V(N_2 \geq N_1)$ and $V(N_1 \geq N_2)$ are needed.

Step 3: The degree of possibility for a convex fuzzy number to be greater than k convex numbers Ni (i=1,2,...,k) can be defined by expression (9);

$$V(N \geq N_1, N_2, \ldots, N_k) = V[(N \geq N_1), (N \geq N_2), \ldots, (N \geq N_k)] \quad (9)$$

$$= \min V(N \geq N_i = 1,2,3,\ldots,k)$$

Assume that Expression (10) is;

$$d'(A_i) = \min V(S_i \geq S_k) \quad (10)$$

for k=1,2,...,n; k ≠ i. So the weight vector is obtained by Expression (11);

$$W' = (d'(A_1), d'(A_2),..., d'(A_m))^T \quad (11)$$

where, A_i (i =1,2,...,n) consists of n elements.

Step 4: Through normalization, the weight vectors are reduced to Expression (12);

$$W = (d(A_1), d(A_2),..., d(A_n))^T \quad (12)$$

where W represents an absolute number.

3.2. Fuzzy TOPSIS Method

The fuzzy TOPSIS calculation most important step is given in Equation (13) (Song et.al., 2013; Viswanadham, 2013), i.e. Creating the Decision Matrix; aggregated ratings are calculated by using Equation (13):

$$\tilde{V}ij = \frac{1}{2} [\tilde{v}_{ij}^1 \oplus \tilde{v}_{ij}^2 \ \oplus \dots \ \tilde{v}_{ij}^s] \quad (13)$$

where $\tilde{v}_{ij}^s$ is the performance rating value obtained from s-th decision maker.

The basic steps of proposed fuzzy TOPSIS method can be described as follows:

Step 1: In the first step, a panel of decision makers (DMs) who are knowledgeable about supplier selection process is established. In a group that has K decision-makers (i.e. D1, D2, ..., Dk) are responsible for ranking (yjk) of each criterion (i.e. C1, C2, …, Cn) in increasing order. Then, the aggregated fuzzy importance weight for each criterion can be described as fuzzy triangular numbers $\tilde{v}j = (a_j, b_j, c_j)$ for k = 1, 2, …, K and j = 1, 2, …, n. The aggregated fuzzy importance weight can be determined as follows:

$$d_j = \frac{min}{k} \{y_{jk}\}, \ b_j = \frac{1}{K} \sum_{k=1}^{K} yjk, \ c_j = \frac{max}{k} \{y_{jk}\} \quad (14)$$

Then, the aggregated fuzzy importance weight for each criterion is normalized as follows:

$\tilde{v}j = (a_{j1}, b_{j2}, c_{j3})$

$$\text{where } v_{j1} = \frac{\frac{1}{dj}}{\sum_{j=1}^{n}\frac{1}{dj}}, \ v_{j2} = \frac{\frac{1}{bj}}{\sum_{j=1}^{n}\frac{1}{bj}}, \ v_{j3} = \frac{\frac{1}{cj}}{\sum_{j=1}^{n}\frac{1}{cj}} \quad (15)$$

Then the normalized aggregated fuzzy importance weight matrix is constructed as $\tilde{V} = (\tilde{v}_1, \tilde{v}_2, \dots, \tilde{v}_n)$

Step 2: A decision matrix is formed.

$$X = \begin{bmatrix} x11 & x12 & \cdots & x1n \\ x21 & x22 & \vdots & x2n \\ \cdots & \cdots & \vdots & \cdots \\ xm1 & xm2 & \dots & xmn \end{bmatrix} \quad (16)$$

Step 3: After forming the decision matrix, normalization is applied. The calculation is done using equations 17 and 18.

$$r_{ij} = \frac{\frac{1}{xij}}{\sqrt{\sum_{i=1}^{m}\frac{1}{xij^2}}} \quad \text{for minimization objective, where } i = 1, 2, \dots, m \text{ and } j = 1, 2, \dots, n \quad (17)$$

$r_{ij} = \frac{xij}{\sqrt{\sum_{i=1}^{m} xij^2}}$ for maximization objective, where i = 1, 2, …, m and j = 1, 2, …, n (18)

Then, normalized decision matrix is obtained as:

$$R = \begin{bmatrix} r11 & r12 & \cdots & r1n \\ r21 & r22 & \vdots & r2n \\ \cdots & \cdots & \vdots & \cdots \\ rm1 & rm2 & \cdots & rmn \end{bmatrix} \quad (19)$$

Step 4: Considering the different weights of each criterion, the weighted normalized decision matrix is computed by multiplying the importance weight of evaluation criteria and the values in the normalized decision matrix. The weighted normalized decision matrix $\tilde{V}$ for each criterion is defined as:

$\tilde{V} = [\tilde{V}_{ij}]_{mxn}$ for i = 1, 2, …, m and j = 1, 2, …, n (20)

Where $\tilde{V}_{ij} = r_{ij} \text{ X } \tilde{o}_j$

Here $\tilde{V}_{ij}$ denotes normalized positive triangular fuzzy numbers.

Step 5: Then fuzzy positive ($\tilde{A}^*$) and fuzzy negative ($\tilde{A}^-$) ideal solutions are determined as follows:

$\tilde{A}^{*} = (\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*)$ where

$\tilde{V}_j^* = \left\{\max_i(vij1),\ \max_i(vij2),\max_i(vij3)\right\}$ and

$\tilde{A}^{-} = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-)$ where

$\tilde{V}_j^- = \left\{\min_i(vij1),\ \min_i(vij2),\min_i(vij3)\right\}$

for i = 1, 2, …, m and j = 1, 2, …, n (21)

Step 6: Then the fuzzy distance of each alternative from fuzzy positive and fuzzy negative ideal solutions are calculated as:

$\tilde{a}_i^* = \sqrt{\sum_{j=1}^{n}(\tilde{v}_j^* - \tilde{v}_{ij}^*)}$ and $\tilde{a}_i^- = \sqrt{\sum_{j=1}^{n}(\tilde{v}_j^- - \tilde{v}_{ij}^-)}$ i = 1, 2, …, m (22)

Step 7: Then the fuzzy closeness coefficient $\tilde{N}$ is determined as:

$\tilde{N}_i = \frac{\tilde{a}_i^-}{\tilde{a}_i^* + \tilde{a}_i^-}$ i = 1, 2, …, m (23)

The fuzzy closeness represents the distances to the fuzzy positive ideal solution and the fuzzy negative ideal solution simultaneously.

Step 8: The fuzzy closeness coefficient defuzzified as follows:

$N_i = \sqrt[3]{N_{i1} \cdot N_{i2} \cdot N_{i3}}$ (24)

3.3. Fuzzy VIKOR Method

The VIKOR method is one of the FMCDM. It was developed by Serafim Opricovic (1990) to solve decision problems with conflicting and non-commensurable criteria, assuming that compromise is acceptable for conflict resolution. VIKOR ranks alternatives and determines the compromise solution closest to the ideal solution. The international recognition of the VIKOR method was due to contribution of Serafim Opricovic and Gwo-Hshiung Tzeng (2004).

In this study Fuzzy-VIKOR method is used to solve problem in a triangular hesitant fuzzy environment. The triangular fuzzy numbers are used to handle imprecise numerical quantities. Fuzzy-VIKOR is based on the aggregating fuzzy merit that represents distance of an alternative to the ideal solution (Incekara,2020). The related steps are as follows (Incekara,2020):

Step 1: Determine the positive triangular ideal solution (PTIS) and the negative triangular ideal solution (NTIS).

$A^+ = \{f_1^+, f_2^+, \dots, f_n^+\}$where

$f_j^+ = \bigcup_{i=1}^{m} f_{ij} = \bigcup_{\gamma 1j \in f1j \dots \gamma mj \in fmj} \quad (\max(\gamma_{1j}^{L}, \dots, \gamma_{mj}^{L}), \max(\gamma_{1j}^{M}, \dots, \gamma_{mj}^{M}), \max(\gamma_{1j}^{U}, \dots, \gamma_{mj}^{U}))$

$A^- = \{f_1^-, f_2^-, \dots, f_n^-\}$where

$f_j^- = \bigcap_{i=1}^{m} fij = \bigcap_{\gamma 1j \in f1j \dots \gamma mj \in fmj} \quad (\min(\gamma_{1j}^{L}, \dots, \gamma_{mj}^{L}), \min(\gamma_{1j}^{M}, \dots, \gamma_{mj}^{M}), \min(\gamma_{1j}^{U}, \dots, \gamma_{mj}^{U}))$ (25)

Step 2: The aggregated fuzzy ratings of alternatives with respect to criterion are calculated by using below Sj and Rj below equations:

$$\tilde{S}_j = \sum_{j=1}^{n} [\tilde{w}_i \; (\tilde{f}_i^* - xij) \,/\, (\tilde{f}_i^* - \tilde{f}_i^-)] \tag{26}$$

$$\tilde{R}_j = \max_i [\, \tilde{w}_i \, (\tilde{f}_i^* - xij) \,/\, (\tilde{f}_i^* - \tilde{f}_i^-)] \tag{27}$$

where w_i are the weights of the criteria expressing their relative importance.

Step 3: Normalization. Compute the values $\tilde{Q}_i$ by using below expressions:

$$\tilde{S}^* = \min_i \tilde{S}_i \,, \; \tilde{S}^- = \max_i \tilde{S}_i \tag{28}$$

$$\tilde{R}^* = \min_i \tilde{R}_i \,, \;\; \tilde{R}^- = \max_i \tilde{R}_i \tag{29}$$

$$\tilde{Q}_i = v \frac{\tilde{S}_i - \tilde{S}^*}{(\tilde{S}^- - \tilde{S}^*)} + (1 - v)\big(\tilde{R}_i - \tilde{R}^*\big)/(\,\tilde{R}^- - \tilde{R}^*) \tag{30}$$

Step 4: Rank the alternatives by sorting the values of S, R and Q in decreasing order which results in three ranking lists.

$$BNP_i = [(u_i - 1) + (m_i - l_i)] /3 + l_i \tag{31}$$

Step 5: Propose as a compromise solution the alternative A’ which is ranked the best by the measure Q(minimum) if the following two conditions are satisfied:

CC1: Acceptable advantage:

$$Q\,(A'') - Q(A') \geq DQ \tag{32}$$

where A” is the alternative with second position in the ranking list by Q; DQ=1/(m-1)

DQ = 1 / (m-1) (if m≤5 ise DQ=0.25); where m is the number of alternatives.

CC2: Acceptable stability in decision: Alternative A” must also be the best ranked by S or/and R. This compromise solution is stable within a decision making process, which could be “voting by majority rule" (when v > 0.5 is needed) or by "consensus" v ≈ 0.5 or with "veto" (v < 0.5). Here v is the weight of the decision making strategy "the majority criteria" or ("maximum group utility"). If one of the two conditions is not satisfied, then a set ofcompromise solutions is proposed, which consists of:

- Alternatives A" and A' if only condition CC2 is not satisfied, or

- Alternatives A', A"… A^m if condition CC1 is not satisfied, A^m is determined by the relation $Q(A^m) - Q(A') \leq DQ$ for maximum m (the positions of these alternatives are "in closeness").

In the study Fuzzy-AHP, Fuzzy-TOPSIS and Fuzzy-VIKOR procedures and related calculations have been coded/solved by using MATLAB program.

3.4. Selection of Natural Gas Energy Resources considering all sectors of World

World's natural gas energy resources in all sectors, i.e. measuring scale, consists of 9 dimensions-main criteria and 39 evaluation factors-sub-criteria. In the process of prioritization of criteria, subcriteria and alternatives, the DMs used in the selection process was consulted. A questionnaire was developed following the methodology proposed for the below methods, which was answered by 32 experts/DMs.

In the study 9 main criteria, i.e. Technical Criteria (C1), Economic Criteria (C2), Natural Gas Hub Criteria (C3), Socio-Political Aspect (C4), Environmental Criteria (C5), Gas Transmission System Availability Criteria (C6), Risk Criteria (C7), Carbon Footprint Criteria (C8), Sustainability Criteria (C9) and 39 related subcriteria are evaluated/assessed by each expert/DM. For the case of prioritization of the criteria, after the aggregation process performed with the answers of the 32 experts, the comparison matrix was obtained. The pairwise comparison matrices for subcriteria and alternatives are calculated. Subsequently, the normalized pairwise comparison matrix of criteria was obtained. The priority vector and the CR for the criteria were obtained. To obtain the other priorities, the same procedure presented for the criteria was applied. In order to facilitate the calculations; which enters the individual judgments of the experts and generates the local and global preferences of all levels of the hierarchical tree (criteria and subcriteria).

Hereunder, World's natural gas energy resources used in all sector's main criteria and related sub-criteria are described:

3.4.1. Technical Criteria

The technical aspect is an important part of choosing natural gas resources. The criteria define the technical relevance of the natural gas related issues/equipments to be implemented according to the scope established in the following subcriteria; i.e. Technology Maturity, Efficiency, Capacity Factor, Spare parts availability, Infrastructure.

3.4.2. Economic Criteria

The economic criteria allow for incorporation of the benefits and costs incurred in implementing the project, according to the scope established in the below subcriteria. The economic aspect is significant for the selection and ranking of usage of natural gas in World. The various sub-criteria have been identified from economic perspectives which are; Investment costs, Operation and Maintenance (O&M) Cost, Resource Potential, Price, Reliability & Feasibility, Payback period.

3.4.3. Natural Gas Hub Criteria

The establishment of a natural gas hub in World can unlock significant benefits, that would support the country's economic, environmental, and energy security goals. While a hub would not bring foreign exchange earnings to countries from exports of its indigenous production and transit gas exports, it would enable such earnings for associated financial and physical services, providing foreign exchange revenues for investors and traders. A hub would also help facilitate energy investments in domestic gas production, especially in shale gas production, where the period from investment to payoff tends to be much briefer than for conventional production. The related sub-criteria are; Gas Resource Diversity, Economic Benefits, Price Stability, Energy Security.

3.4.4. Socio-Political Aspect

The socio-political aspect is crucial for the natural gas projects. Similarly, this aspect has important sub-criteria and each of these has been described here: Public Acceptance, Energy Security, Institutional Arrangement, Regulatory Mechanism.

3.4.5. Environmental Criteria

The environmental criteria incorporate the impact of the implementation of the energy project/system in the environment, according to the scope established in the following subcriteria; GHG Emissions, Pollution, Requirement of Land, Visual Impact, Hazardous Waste, Impact on Environment.

3.4.6. Gas Transmission System Availability Criteria

The gas transmission system availability is an important part of choosing an optimal project. Since it will reduce the cost of energy projects significantly. The related sub-criteria are; Gas Transmission Line System Availability, Efficiency, Capacity Factor.

3.4.7. Risk Criteria

With the risk criteria, the objective is to incorporate the risks to which the system is exposed to the occurrence of unforeseen situations but that can significantly affect its functioning. The related sub-criteria are; Natural Phenomena, Investment Risk, Storage and Interconnections Risks, Technological Obsolescence.

3.4.8. Carbon Footprint Criteria

A carbon footprint is the total greenhouse gas (GHG) emissions caused by an individual, event, organization, service, place or product, expressed as carbon dioxide equivalent of fuels. Greenhouse gases, including the carbon-containing gases carbon dioxide and methane, can be emitted through mainly from the burning of fossil fuels, and then the production and consumption of food, manufactured goods, …etc and other services. The average carbon footprint for a person in US is 16 tons, one of the highest rates in the world. Globally, the average is closer to 4 tons. To have the best chance of avoiding a 2℃ rise in global temperatures, the average global carbon footprint per year needs to drop under 2 tons by 2050. The related sub-criteria are; GHG Emissions, Carbon dioxide and Methane Emissions.

3.4.9. Sustainability Criteria

EU meet its greenhouse gas reductions targets, whereas agricultural production is still necessary in EU, it may lead to the extension of agriculture land into non-cropland, possibly including areas with high carbon stock such as forests, wetlands and peatlands. This process is known as indirect land use change (ILUC). As this may cause the release of CO_2 stored in trees and soil, indirect land use change risks negating the greenhouse gas savings that result from increased biofuels. In 2015 new rules came into force to reduce the risk of indirect land use change in EU– in both the Renewable Energy Directive 2009/28/EC and the Fuel Quality Directive 2009/30/EC. The related sub-criteria are; Indirect Land Usage, Environmental Performance Index, Environmental Sustainability Index, Energy for Development Index.

3.5. Determining the evaluation criteria weights with Fuzzy AHP Approach

Firstly, each DM practiced pair-wise comparisons of World's natural gas demand's dimensions and evaluation factors by using fuzzy AHP. Using the survey data acquired from these experts, integrated pair-wise comparison matrices are formed by combining all expert opinions. Thus, the pair-wise comparison values are converted to triangular fuzzy numbers and fuzzy pair-wise comparison matrices are created, presented in Table 2.

$$l_{ij} = \min_k\{a_{ijk}\} \qquad n_{ij} = \frac{1}{K}\sum_{j=1}^{K} b_{ijk} \qquad u_{ij} = \max_k\{c_{ijk}\} \tag{33}$$

Table 2. Fuzzy mutual criteria comparison

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	(1, 1, 1)	(3, 5, 7)	(1, 3, 5)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 11)	(7, 9, 11)
C2	(1/7, 1/5, 1/3)	(1, 1, 1)	(1, 3, 5)	(5, 7, 9)	(5, 7, 9)	(7, 9, 11)	(3, 5, 7)	(7, 9, 11)	(7, 9, 11)
C3	(1/5, 1/3, 1)	(1/5, 1/3, 1)	(1, 1, 1)	(3, 5, 7)	(7, 9, 11)	(7, 9, 11)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
C4	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/5)	(1/7, 1/5, 1/3)	(1, 1, 1)	(3, 5, 7)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(7, 9, 11)
C5	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/5)	(1/11, 1/9, 1/7)	(1/7, 1/5, 1/3)	(1, 1, 1)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(1, 3, 5)

C6	(1/9, 1/7, 1/5)	(1/11, 1/9, 1/7)	(1/11, 1/9, 1/7)	(1/7, 1/5, 1/3)	(1/5, 1/3, 1)	(1, 1, 1)	(1, 7, 9)	(1, 7, 9)	(1, 7, 9)
C7	(1/9, 1/7, 1/5)	(1/7, 1/5, 1/3)	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/5)	(1/7, 1/5, 1/3)	(1/9, 1/7, 1)	(1, 1, 1)	(1/9, 1/7, 1/5)	(7, 9, 11)
C8	(1/11, 1/9, 1/7)	(1/9, 1/7, 1/5)	(1/7, 1/5, 1/3)	(1/5, 1/3, 1)	(1/5, 1/3, 1)	(1/9, 1/7, 1)	(5, 7, 9)	(1, 1, 1)	(1/9, 1/7, 1/5)
C9	(1/11, 1/9, 1/7)	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/5)	(1/5, 1/3, 1)	(1/9, 1/7, 1)	(1/11, 1/9, 1/7)	(5, 7, 9)	(1, 1, 1)

After acquiring the fuzzy comparison matrices, importance weights of natural gas demand's dimensions; evaluation criteria is calculated by FAHP method. According to the calculated criteria weights for natural gas demand's weights; the most important evaluation dimension/main-criteria is "Environmental Criteria" with 0.158 importance weight, the second important evaluation dimension is "Economical Criteria" with 0.129 importance weight and the third important evaluation dimension is "Sustainability Criteria" with 0.118 importance weight.

3.6. Ranking the alternatives by Fuzzy TOPSIS & Fuzzy-VIKOR methods

For the evaluation of World's natural gas sector's demands, Fuzzy-TOPSIS & Fuzzy-VIKOR approach are conducted with the collected data of DM's surveys/interviews. Primarily, the linguistic variables of the alternatives are created. By the help of criteria weights, Fuzzy-TOPSIS & Fuzzy-VIKOR methods steps are performed/completed and World's natural gas sectors that affect demand are ranked from the best to the worse. Primarily, the linguistic variables of the alternatives are created thusly in Table 3.

Table 3. Linguistic Variables of the Alternatives in Fuzzy TOPSIS method

Criteria / **Sectors**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
Household	SA	A	A	LA	LA	SA	SDA	LA	SDA
Industry	SA	A	A	A	A	A	DA	A	SDA
Energy	SA	SA	SA	SA	SA	LA	SDA	DA	DA
Transportation	A	LA	LA	A	LA	SA	LA	SDA	SDA
Public service	SA	SA	A	SA	LA	LA	DA	A	SDA

Fishing, agriculture, forestry	A	A	SA	SA	LA	A	DA	A	DA

Then Fuzzy TOPSIS method is used for the ranking of 6 main natural gas sectors according to the relative distance values of alternatives (CCi). Since natural gas sector has 10 values between 2020 to 2030, the values of indicators are set into triangular fuzzy numbers.

Utilizing the method of triangular fuzzy numbers, the fuzzy numbers of financial ratios are obtained (Incekara,2019; 2020). After applying the steps in Fuzzy-TOPSIS method, i.e. defined steps in above Section, sectors' performance scores are ranked. The ranking of the alternatives is as follows: Energy (first ranked), Industry (second ranked), Household (third ranked). The reason of it is in energy sector; natural gas-fired power plants has operational flexibility and allows natural gas to respond to both seasonal and short-term demand fluctuations and to enhance electricity supply security in power systems.

In Fuzzy-VIKOR method, by ranking the preference order by the help of DMs/experts and by compromise solution; Energy sector is the best alternative. From the comparison table we find that the values of Q1 increases as the value of weight v increases, the values of Q3 decreases as the value of weight v increases while values of Q1 remains unaltered. The ranking of the alternatives is not affected by the change of weights.

4. CONCLUSION AND DISCUSSIONS

Natural gas is the fastest growing fossil fuel, accounting today for 23% of global primary energy demand and nearly a quarter of electricity generation. Being the cleanest burning fossil fuel, natural gas provides a number of environmental benefits compared to other fossil fuels, particularly in terms of air quality and greenhouse gas emissions. The natural gas market is becoming increasingly globalized, driven by the availability of shale gas and the rising supplies of flexible liquefied natural gas.

Consumers increasingly tend towards natural gas as a low-cost and cleaner source of power and transportation. In resource-rich regions, natural gas increasingly takes share from coal and fuel oil in power generation and as a feedstock for chemicals in the World. Despite the decline of global energy intensity due to Covid pandemic, natural gas demand grows by more than 70% between 2014 and 2040.

In this study, fuzzy mathematical model (by using fuzzy-AHP/fuzzy-TOPSIS/fuzzy-VIKOR) is developed to calculate Worlds natural gas demand under high and low scenarios. Worlds natural gas energy resources in all sectors, i.e. measuring scale, consists of 9 dimensions-main criteria and 39 evaluation factors-sub-criteria. In the process of prioritization of criteria, subcriteria and alternatives, the DMs used in the selection process was consulted. A questionnaire was developed following the methodology proposed for the below methods, which was answered by 32 experts/DMs.

And in the study 9 main criteria, i.e. Technical Criteria (C1), Economic Criteria (C2), Natural Gas Hub Criteria (C3), Socio-Political Aspect (C4), Environmental Criteria (C5), Gas Transmission System Availability Criteria (C6), Risk Criteria (C7), Carbon Footprint Criteria (C8), Land Usage Criteria (C9), and 39 related subcriteria are evaluated/assessed by each expert/DM. For the case of prioritization of the criteria, after the aggregation process performed with the answers of the 32 experts, the comparison matrix was obtained. The pairwise comparison matrices for subcriteria and alternatives are calculated. Subsequently, the normalized pairwise comparison matrix of criteria was obtained. The priority vector and the CR for the criteria were obtained. To obtain the other priorities, the same procedure presented for the criteria was applied. In order to facilitate the calculations; which enters the individual judgments of the experts and generates the local and global preferences of all levels of the hierarchical tree (criteria and subcriteria).

In the study, firstly, each DM practiced pair-wise comparisons of World's natural gas demand's dimensions and evaluation factors by using fuzzy AHP. Using the survey data acquired from these experts, integrated pair-wise comparison matrices are formed by combining all expert opinions. Thus, the pair-wise comparison values are converted to triangular fuzzy numbers and fuzzy pair-wise comparison matrices are created. After acquiring the fuzzy comparison matrices, importance weights of natural gas demand's dimensions; evaluation criteria is calculated by the FAHP method. According to the calculated criteria weights for natural gas demand's weights; the most important evaluation dimension/main-criteria is "Environmental Criteria" with 0.158 importance weight, the second important evaluation dimension is "Economical Criteria" with 0.129 importance weight and the third important evaluation dimension is "Sustainability Criteria" with 0.118 importance weight.

In the study Fuzzy-TOPSIS and Fuzzy-VIKOR method is used for the ranking of 6 main natural gas sectors according to the relative distance values of alternatives. After applying the steps in Fuzzy TOPSIS method, i.e. defined steps in Section 3.2., natural gas sector's performance scores are ranked. The ranking of the alternatives/sectors is as follows: Energy (first ranked), Industry (second ranked), Household (third ranked), Transportation (fourth ranked), Public service, Fishing, agriculture, forestry. The reason of the selection of energy is; in energy sector gas-fired power plants has operational flexibility and allows natural gas to respond to both seasonal and short-term demand fluctuations and to enhance electricity supply security in power systems.

In Fuzzy-VIKOR method, , i.e. defined steps in Section 3.3., by ranking the preference order by the help of DMs/experts and by compromise solution; "Energy Sector" is the best alternative. From the comparison table we find that the values of Q1 increases as the value of weight v increases, the values of Q3 decreases as the value of weight v increases while values of Q1 remains unaltered. The ranking of the alternatives is not affected by the change of weights.

The results show that World natural gas sector's supply long term contracts should have been secured from more diversified fossil fuel sources of energy supply and number of energy/natural gas hubs in the World should be increased. The related natural gas investments and related long-term contracts (not take-or-pay contracts) were needed to meet World's and World's regions' growing energy needs which is presented in Table 4 and Figure 3.

In the study it is calculated as; in High-Demand Scenario (Scenario-High) it will increase by 2,5 % per year from 2020 to 2030 and will increase by 1,77 % per year from 2030 to 2040, as presented in Table 4. In Low-Demand Scenario (Scenario-Low) it will increase by 0,4 % per year from 2020 to 2030 and will increase by 1,3 % per year from 2030 to 2040. It is the only fossil fuel expected to grow beyond 2030.

In the study natural gas continues to outperform other fossil fuels, i.e. coal and oil, and some of the renewables, i.e. geothermal and biomass, in two Scenario, i.e. High, and Low Scenario. Since it is environmental friendly resource compared to other fossil fuels.

Scenario-High: In the Scenario market forces drive high economic growth in a competitive globalized world shaped by market mechanisms. International Renewable Energy Agency (IRENA) argues that the rapid deployment of renewable energy (to increase from around 65%

of the primary energy supply in 2050) is one of the essential measures to tackle the energy challenge. Therefore, in Scenario-High high natural gas growth rate, which is approx. 47% increase, between 2020 and 2040 is assumed and reached 5.650 bcm in 2040. In the Scenario, natural gas is seen as low-cost cleaner fuel for power generation and transport. In the market-driven world represented by Scenario-High, natural gas is supported by strong economic growth in a globalized economy, increasing awareness of environmental issues and an active private sector. It is abundant and accessible and, as a result, by 2040 is the world's the main primary energy source.

Scenario-Low: In the Scenario moderate economic growth, rising energy efficiency, more stringent emissions standards and rapid deployment of renewables dampen growth for natural gas. In Scenario-Low; low natural gas growth rate, which is approx. 18,5% increase, between 2020 and 2040 is assumed and reached 4.550 bcm in 2040. For the year 2050 and beyond WEO forecasted that the countries will focus on decarbonisation, and then natural gas has in the medium term a continued role as a major contributor to the decarbonisation of the electricity sector through coal substitution whereas in the longer term it is progressively replaced by renewables, starting with mature markets.

In addition, all WEO's scenarios predict the growing of global natural gas demand while retaining a share between 20% and 35% of global energy mix in 2030 and 2040. EIA (2020) predict natural gas to rise to 39 percent by 2050, which is higher than the expected 31 % of electricity production by renewables.

In Scenario-High calculated natural gas demand projections by region in 2030 and in 2040 is presented in Table 4 and Figure 3.

Table 4. Natural gas demand by region in 2030 and in 2040 (Scenario-High)

Region	Natural Gas Demand in 2030	Natural Gas Demand in 2040
North America	1250	1350
Central and South America	250	300
Europe	650	650
Middle East	750	920
Eurasia	650	680
Asia Pacific	1250	1750

In Scenario-High natural gas demand grows by more than 47,1% between 2020 and 2040. In Scenario-Low natural gas demand grows by more than 18,5% between 2020 and 2040.

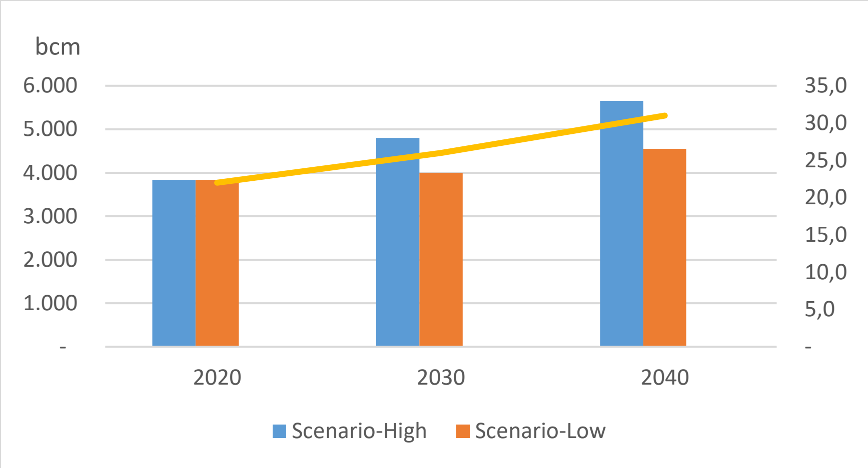

Figure 3. World's Natural Gas Demand (bcm) and Market Share

After an approx. 4% drop in 2020, natural gas demand is expected to progressively recover in 2021 as consumption returns close to its pre-COVID level in mature markets, while emerging markets benefit from economic rebound and lower natural gas prices. The world's natural gas demand is estimated to fall in 2020 down to 3.840 billion cubic meters (bcm) whereas in 2018 it is 3.805 billion cubic meters (bcm). The impact of the 2020 crisis is expected to have repercussions on the medium-term growth potential, resulting in about 160 bcm of increase growth in Scenario-Low and about 960 bcm of increase growth in Scenario-High over the forecast period, between 2020 and 2030. And in 2040 it reached 5.650 bcm in Scenario-High and 4.550 bcm in Scenario-Low. In the study in Scenario-High natural gas demand grows by more than 47% between 2020 and 2040 and in Scenario-Low natural gas demand grows by more than 18,5% between 2020 and 2040.

Due to Covid pandemic, global natural gas consumption has fallen in 2020 in major markets even, i.e. declined by approx. 4% in 2020. Natural gas will be the strongest-growing fossil fuel and in Scenario-High it will increase by approx. 25 % from 2020 to 2030 and will increase by approx. 18 % between 2030 and 2040. In Scenario-Low it will increase by approx. 4 % from 2020 to 2030 and will increase by approx.14 % from 2030 to 2040. It is the only fossil fuel expected to grow beyond 2030 since it is clean energy source.

In Scenario-High natural gas demand by region is calculated/projected as follows: in 2030 North America 1250 bcm, Central and South America 250 bcm, Europe 650 bcm, Middle East 750 bcm, Eurasia 650 bcm, Asia Pacific 1250 bcm. And in 2040 it is calculated as follows: North America 1350 bcm, Central and South America 300 bcm, Europe 650 bcm, Middle East 920 bcm, Eurasia 680 bcm, Asia Pacific 1750 bcm.

DMs are estimated/forecasted that investment costs of natural gas power plants due to technological improvements in gas turbines and operating costs of existing natural gas-fired power plants within the next 10 to 20 years will decrease. The increase of usage of natural gas is estimated by DMs. The reasons of it is: US Geological Survey Institute recently announced new estimates of reachable gas in Appalachia and upstate New York and discovery of new shale gas reserves in US, one of the main LNG exporter, that are nearly triple the export estimates. And many major oil and gas producers tout sustainability programs to dramatically reduce the carbon footprint of their operations. Whereas those pledges are hard to square with their proclamations about natural gas. Natural gas will expand its role, led by growth in energy, i.e. electricity generation, and industrial output. The usage of natural gas will continue to grow in transportation, household, i.e. mainly heating and lighting, and power industries. The study shows that EU's, US's and Word's decarbonizing energy aim, i.e. curbing the emissions trajectory to net zero, by 2050 is nearly impossible. EU's and some US states' goal to reach zero carbon emissions by 2050 is postponed to year 2100.

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