Available online at www.sciencedirect.com
ScienceDirect
Energy Conversion and Management 49 (2008) 2345–2353
ENERGY CONVERSION & MANAGEMENT
www.elsevier.com/locate/enconman

Evaluation of natural gas supply options for Southeast and Central Europe: Part 2. Multi-criteria assessment

Naim H. Afgan [a], Maria G. Carvalho [b], Petros A. Pilavachi [c], Nelson Martins [d,*]

[a] Technical University of Lisbon, Av. Rovisco Pais 1049-001, Lisbon, Portugal
[b] BEPA – Bureau of European Policy Advisers, European Commission, Brussels, Belgium
[c] University of Western Macedonia, Kozani, Greece
[d] University of Aveiro, Engenharia Mecânica, Campus Santiago, 3810-193 Averio, Portugal

Received 3 June 2007; accepted 14 January 2008
Available online 7 March 2008

Abstract

Decision making methods are used as a tool for the selection of alternatives to be evaluated on the basis of several criteria. Evaluation of the potential routes for natural gas supply to the Southeast and Central European countries is studied using single and multi-criteria evaluation. The potential options included in this analysis are the: Yamal Route; Nabucco Route; West Balkan Route; LNG Neum Route; and Gas by Wire Route. In part 1, the paper was devoted to the definition of the indicators and to single indicator analysis. In part 2, the analysis is based on multi-criteria evaluation, which comprises the possibility to assess the options under predefined constraints amongst indicators. The paper also describes different methods used for multi-criteria evaluation. This analysis focuses on cases with different priorities defined among individual weighting coefficients with the others having the same value. It was shown that all options under specific constraints can be qualified as promising in the decision making process. It is also concluded that favourite indicator constraints may exaggerate some options.
© 2008 Elsevier Ltd. All rights reserved.

Keywords: Natural gas route evaluation; Decision making methods; Southeast Europe

1. Introduction

Decision making methods are used as a tool for selection and ranking of alternatives on the basis of an evaluation with several criteria. Extensive studies devoted to the overview of multi-criteria decision methods, applied to the analysis of sustainable energy systems can be found at Refs. [1,2]. Decisions are, most times, based on a trade off or compromise amongst a number of criteria, which are in conflict with each other. These methods provide a better understanding of the inherent features of decision problems, promote the role of participants in decision making processes, facilitate compromise and collective decisions and provide a good platform for understanding the perception of models by analysts in a realistic scenario. A single criterion approach, aimed to identify the most energy efficient supply option at low cost has been quite popular. However, in the 1980s, a growing environmental awareness has slightly modified the above decision framework [3]. The need to incorporate environmental and social considerations in energy planning resulted in an increasing use of multi-criteria approaches.

Multi-attribute decision making and the multi-objective decision making are among the multi-criteria decision making methods. Multi-objective linear programming is a planning methodology used for illustrating the trade off between environmental and economic parameters and for assisting in the selection of a compromise solution [4–6]. This was popular in energy planning with conventional fuels in the 1970s.

* Corresponding author. Tel.: +351 234378171; fax: +351 234370953.
E-mail address: nmartins@mec.ua.pt (N. Martins).

0196-8904/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enconman.2008.01.024

Nowadays, renewable energy sources are being promoted for a wide variety of applications worldwide. This compels planners and decision makers to identify the barriers for penetration and suggest interventions to overcome them. The role of different actors in decision making, thus, becomes important. Methods of group decisions are, therefore, of primary interest for implementation of the decision sciences in real life problems.

1.1. Multi-criteria decision making (MCDM)

Multi-criteria decision making is a well known branch of decision making. It is a branch of a general class of operational research models, which deal with decision problems under the presence of a number of criteria. This major class of models is very often called MCDM. This is further divided into multi-objective decision making (MODM) and multi-attribute decision making (MADM) methods [7]. Multi-criteria decision making (MCDM) methods deal with the process of making decisions in the presence of multiple objectives. A decision maker is required to choose among quantifiable or non-quantifiable and multiple criteria.

There are several methods in each of the above categories. Priority based, outranking, distance based and mixed methods are also applied to various problems. Each method has its own characteristics, and the methods can also be classified as deterministic, stochastic and fuzzy. There may be combinations of the above methods. Depending upon the number of decision makers, the methods can be classified as single or group decision making methods. Decision making under uncertainty and decision support systems are also prominent decision making techniques [8].

1.2. The elimination and choice translating reality (ELECTRE)

The ELECTRE method is capable of handling both quantitative and qualitative discrete criteria and provides complete ordering of the alternatives. The problem is to be formulated in such a way that it chooses alternatives that are preferred over most of the criteria and that do not cause an unanticipated level of discontent for any of the criteria. Concordance, discordance indices and threshold values are used in this method. Based on these indices, graphs for strong and weak relationships are developed. These graphs are used in an iterative procedure to obtain the ranking of the alternatives [9]. This index is defined in the range 0–1, provides a judgment on the degree of credibility of each outranking relation and represents a test to verify the performance of each alternative. Finally, the ELECTRE method yields a whole system of binary outranking relations between the alternatives. Because the system is not necessarily complete, the ELECTRE method is sometimes unable to identify the preferred alternative. It only produces a core of leading possibilities by eliminating lesser alternatives in a decision making problem [10].

1.3. Preference ranking organization method for enrichment evaluation (PROMETHEE)

The PROMETHEE method uses the outranking principle to rank the alternatives and combines ease of use and decreased complexity. It performs a pair wise comparison of the alternatives in order to rank them with respect to a number of criteria. Brans et al. [11] have offered six generalized criteria functions for reference, namely, usual criterion, quasi-criterion, criterion with linear preference, level criterion, criterion with linear preference and indifference area and Gaussian criterion. The method uses a preference function $Pj(a,b)$, which is a function of the difference δj between two alternatives for any criterion j, i.e. $\delta j = f(a,j) - f(b,j)$, where $f(a,j)$ and $f(b,j)$ are values of the two alternatives a and b for criterion j. The indifference and preference thresholds q' and p' are also defined depending upon the type of criterion function.

1.4. Analytical hierarchy process (AHP)

The analytical hierarchy process was developed by Saaty [12,13]. The essence of the process is the decomposition of a complex problem into a hierarchy with goal (objective) at the top of the hierarchy, criteria and sub-criteria at levels and sub-levels of the hierarchy and decision alternatives at the bottom of the hierarchy. The elements at a given hierarchy level are compared in pairs to assess their relative preferences with respect to each of the elements at the next higher level. The procedure is repeated upwards for each level until the top of the hierarchy is reached. The overall weight coefficient with respect to the goal for each decision alterative is then obtained. The alterative with the highest weight coefficient value should be taken as the best alternative. One of the major advantages of the AHP is that it calculates the inconsistency index as a ratio of the decision maker's inconsistency and randomly generated index. This index is important for the decision maker to assure him that his judgments were consistent and that the final decision is well made.

1.5. Multi-attribute utility theory (MAUT)

Multi-attribute utility theory takes into consideration the decision makers' preference in the form of the utility function that is defined over a set of attributes. The utility value can be determined through single attribute utility functions followed by verification of preferential and utility dependent conditions and derivation of multi-attribute utility functions. The utility function can be either additively separable or multiplicatively separable with respect to single attribute utility. The multiplicative equation for the utility value is defined as follows:

$$1 + ku(x_1, x_1, x_1 \ldots x_n) = \prod_{j=1}^{n}(1 + kk_j u_j(x_j)) \quad (1)$$

where j is the index of each attribute, k is the overall scaling constant (greater than or equal to -1), $u(\ldots)$ is the overall utility function operator, kk, is the scaling constant for attribute j and $u_j(\ldots)$ is the utility function operator for each attribute [14].

2. Multi-criteria evaluation of natural gas supply options

2.1. ASPID – analysis and synthesis of parameters under information deficiency method

"Uncertainty": "ambiguity," "fuzziness" and other similar concepts are quite usual in multi-criteria evaluation of real large scale systems, time long projects, variants of crucial financial decisions and other complex objects. Thus, it seems rather natural to use the flexible language and apparatus of fuzzy sets theory for a new multi-criteria decision making technique expounding and representing the technique's computer realization – a decision support system shell (DSSS) "ASPID-3W" (analysis and synthesis of parameters under information deficiency), which operates in Windows 95 and is widely used to evaluate different complex objects under uncertainty [15,16].

The decision support system shell (DSSS) "ASPID-3W" is based on the following reasoning. It is supposed that complex objects are identified with vectors $x(j) = (x_1(j), \ldots, x_n(j))$, $x_1(j) \subseteq E_1 x(j) \subseteq E_n$, where $x_1(j)$ is a value of the ith initial parameter x_i for the jth complex object, $i = 1, \ldots, n, j = 1, \ldots, k$ (where k is the number of objects under investigation). In other words, the jth complex object is identified with a vector $x(j) = (x_1(j), \ldots, x_n(j))$, which is a value of the n-variable vector $x' = (x_1, \ldots, x_n)$ of the initial parameters. All objects under consideration compose a finite set $X = \{x(j), j = 1, \ldots, k\}$.

The subject of evaluation is complex objects quality (efficiency, reliability, productivity and others). Taking into account that the main goal of objects evaluation is decision making, that is, choosing the most preferable object(s), we can use the word "preferability" for any quality under evaluation. This preferability of complex objects is evaluated by a number of criteria (e.g. q_i; $i = 1, \ldots, m$) with each of them being a function of the initial parameters vector $x_i = (x_1, x_2, \ldots, x_n)$, $q = q(x_i) = q(x_1 \cdot x_n)$, $i = 1, \ldots, m$. Here, we deal with the simple case where every particular criterion q_i is a function of only one relevant initial parameter x_i:$q = q(x_i)$, $i = 1, \ldots, m = n$.

A function $q_i = (x_i)$ may be treated as a particular membership function of a fuzzy set of objects that are preferable from the point of the ith criterion's. Without loss in generality, it can be supposed that all particular criteria are normalized, that is, the ith criterion meets the inequality $1 \geqslant q \geqslant 0$. As this normalization takes place, the minimal value $q(j) = 0$ of the ith criterion is correlated with object $x(j)$, which has minimal preference, and the maximal value $q_i(j) = 1$ is correlated with an object $x(j)$, which has maximal preference. Thus, the membership function sets up a correlation between an object $x(j) = (x_i(j), \ldots, x_m(j))$ from the set X and its multi-criteria estimation $q(x(j)) = q(x1(j), \ldots, xn(j))$, $q(j) = (q_1(j), \ldots, q_m(j))$ where $q_i(j) = q_i(x)$, $i = 1 \ldots, m$, $j = 1 \ldots, k$.

The fuzzy sets synthesis technique may be interpreted in probabilistic terms. An uncertain choice of a weight vector $w = (w_1, w_2, \ldots, w_m)$ from the set $W(I; m, n)$ may be modelled by a random choice, which is determined by the uniform distribution of the set. Such randomization of uncertainty gives random weight coefficients $w_1(I), \ldots, w_n(I)$. The fuzzy sets synthesis technique outlined is a choice of a synthesizing (aggregative) function. Usually, a modification of the generalized weighted mean:

$$Q_\varphi(q) = Q_\varphi(q, w) = Q_\varphi(q_1 \ldots q_m, w_1 \ldots w_m) = \varphi^{-1} \sum_{i=1}^{m} w_i \varphi(q_i) \quad (2)$$

is selected as an aggregative function. In this formula, φ is an arbitrary monotonically increasing continuous function, and $w = (w_1, \ldots, w_m)$, $w \geqslant 0$, $w_1 + w_2 + \cdots + w_m = 1$, is a vector of weight coefficients $w_1, w_2, \ldots, w_m$ (weight vector).

A weight coefficient w_i is a measure of the relative significance of the corresponding particular criterion q_i for aggregative estimation $Q(q(j))$ of the general preferability of an object $x(j)$.

The generalized weighted mean $Q = (q, w)$ is a very flexible tool and many practically wide spreading synthesizing functions may be treated as its special case. That is, if φ is selected as an exponential function $\varphi(z) = z^\lambda$, $z > l$, $\lambda > 0$, then we have an exponential weighted mean:

$$Q_\lambda(q, w) = \left(\sum_{i=1}^{m} w_i q_i^\lambda\right)^{\frac{1}{\lambda}} \quad (3)$$

Interpretation of the mathematical tool presented in this section can be outlined in the form of the following procedure.

What is a base for generating the most popular synthesizing function?

That is, if $\lambda = 1$, then $Q(q, w)$ transforms into an additive function (weighted arithmetic mean):

$$Q = (q, w) = \sum_{i=1}^{m} w_i q_i \quad (4)$$

The General Index is formed through the following procedure:

1. Formation of vectors $x = (x_1, \ldots, x_m)$ of all input attributes (characteristics) that are necessary for full evaluation of the quality of the options under consideration. Attributes are expressed by four groups of indicators: resource indicators, environmental indicators, social indicators and economic indicators.

2. Formation of vectors of specific criteria $q = (q_1, \ldots, q_m)$ by which input attributes (indicators) $x_1, \ldots, x_m$ are to be evaluated.
3. Introducing weighting factors for each indicator, in the multi-criteria assessment, the General Sustainability Index for the options under consideration is defined. With multiplication of individual indicators with their respective weighting coefficients, the participation of individual criteria is expressed. The additive function of the product of indicators with their respective weighting coefficient gives the General Index, as per Eq. (3).
4. In order to define the weight coefficient vector, randomization of uncertainty is introduced. Randomization produces stochastic realizations from corresponding sets of functions and a random weight vector. It is assumed that the measurement of the weight coefficients is accurate to within a step $h = 1/n$, with n a positive integer. In this case, the infinite set of all possible vectors may be approximated by the finite set $W(m,n)$ of all possible weight vectors with discrete components. In our case, $m = 5$, and $n = 40$ will be used so that the total number of elements of the set $W(m,n)$ is $N(m,n) = 92{,}251$.
5. As the final result of this procedure, the list of priorities measured by the General Index of options under consideration is obtained.

2.2. Multi-criteria analysis of potential options for natural gas supply

An individual criterion for evaluation of the potential gas transport options is leading to a limited guidance for the respective decision making process. In this respect, individual indicators are leading to the priorities of specific options, which will strongly depend on the selected indicator.

It is of interest to investigate the effect of multi-indicators in order to establish the priorities of the options under consideration. A trivial solution can be obtained if it is assumed that all indicators equally participate in validation of an individual option. Another possibility is that the rating among options is established from the most probable combination of the weighting factors in all potential combinations. For multi-criteria analysis, there are a large number of combinations describing potential situations of weighting factors. In order to overcome this arbitrariness in the evaluation of these options, the multi-criteria evaluation method is introduced [15,16,18]. This method is based on the numerical values of the indicators used in the multi-criteria analysis and is presented in Table 1 [17].

The multi-criteria assessment method is based on the decision making procedure [17] reflecting the combined effect of all criteria under consideration and is expressed in the form of a General Index of Sustainability. A selected number of indicators is taken as the measure of the criteria comprising specific information of the options under consideration [19]. The procedure aims to express the property of the options by a respective set of indicators, (Fig. 1).

The first step in the preparation of the data for the multi-criteria sustainability assessment is the numerical allocation of the data. This step consists in the formation of particular membership functions $q_1(x_1), \ldots, q_m(x_m)$. For every Indicator x_i, we have to (1) fix two values MIN(i), MAX(i); (2) indicate if function $q_i(x_i)$ is decreasing

Table 1
Indicators

Option				Indicators				
	Designation	Capacity Bcm/yr	Length km	Environment 10^3 t/yr	NG Cost Euro/10^3 m^3	Transport Cost Euro/10^3 m^3	Investment Euro/m^3/yr	NG Demand 10^3 m^3/capita/yr
1	Yamal Gas Route	30	4000	9930	90.47	40.50	0.91	1.00
2	Nabucco Project	20	3600	6400	37.00	79.00	0.50	0.65
3	West Balkan Route	15	3400	3500	37.00	96.60	0.60	0.31
4	LNG Terminal Neum	10	600 + 1600	2380	47.20	38.95	0.15	0.53
5	Gas by Wire	15	5000	3250	37.00	73.60	0.24	0.437

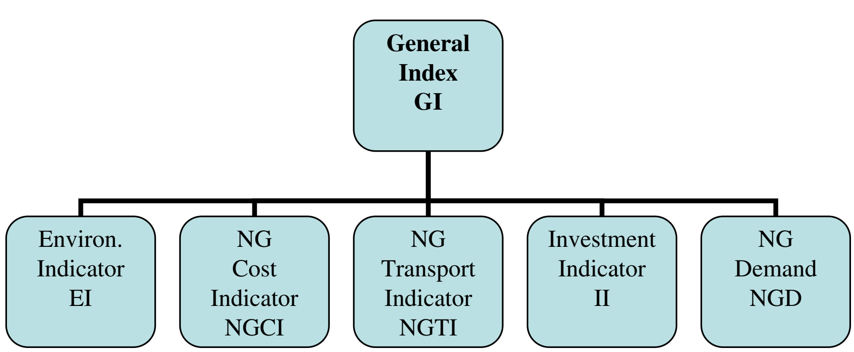

Fig. 1. Graphical presentation of indicators.

or increasing with argument x_i increasing; (3) choose the exponent value λ in equation:

$$q_i(x_i) = \begin{cases} 1, & \text{if } x_i \leqslant \text{MIN}(i), \\ \left(\frac{\text{MAX}(i)x_i - x_i}{\text{MAX}(i)-\text{MIN}(i)}\right)^{\lambda}, & \text{if MIN}(i) < x_i \leqslant \text{MAX}(i), \\ 0, & \text{if } x_i > \text{MAX}(i) \end{cases} \quad (5)$$

for the decreasing function $q_i(x_i)$.

The functions $q_1(x_1),\ldots,q_m(x_m)$ are calculated and produce a matrix $(q_i^{(j)})$ having $i=1,\ldots,m$ and $j=1,\ldots,k$, where an element $q_i^{(j)}$ is a value of the ith particular criterion for the j th option. In this analysis, it is assumed that linear functions $q_1(x_1),\ldots,q_m(x_m)$ are used.

Decreasing functions are adopted for the q_1, q_2, q_3 and q_4 membership functions.

In Table 2, the values of these functions $q_1(x_1),\ldots,q_m(x_m)$ are presented.

In order to define the weight coefficient vectors, randomization of uncertainty is introduced. It is assumed that the weight coefficients are accurate to within a step of $h = 1/n$ where n is a positive integer. In this case, the infinite set of all possible vectors may be approximated by the finite set $W(m,n)$ of all possible weight vectors with discrete components. In the present case, m is set to 5 and n is set to 40 so that the total number of elements $N(m,n)$ of set $W(m,n)$ is 135751.

Non-numeric, inexact and incomplete information is used for reduction of the set $W(m,n)$ of all possible vectors w to obtain the discrete components set $W(I,n,m)$. It is defined as a number of constraints reflecting non-numeric information about the mutual relations among the criteria under consideration.

Table 2
Normalized indicators

Option	Environment	NG Cost	Transport Cost	Investment cost	NG Demand
Yamal Route	0.000	0.000	0.368	0.000	1.000
Nabucco Route	0.264	0.806	0.809	0.485	0.636
West Balkan Route	0.787	0.806	1.000	0.279	0.000
LNG Terminal Neum	0.989	0.563	0.000	1.000	0.381
Gas by Wire	0.832	0.806	0.698	0.947	0.189

3. Results

3.1. Selection of cases

For evaluation of any complex system by the ASPID method, appropriate parameters, needed for its application have to be selected.

As a fist step we have to select a number of criteria and respective indicators. In this analysis, $m = 5$ will be used. Randomization of the weight coefficient will need the decision of scale $n = 40$. Finally, we have to select constraints to impose on the analysis and evaluation of the system under consideration.

In this exercise, two groups of constraints are defined, namely: a group with priority given to the single indicator, while the other indicators have equal values; and a second group with all indicators defined by the internal preference amongst the criteria.

3.1.1. Group 1

In evaluation of the priority list amongst the alternative options, some cases have to be selected to represent potential constraints between the indicators. This means that the cases that are to be representative for the decision making procedure have to be defined. The evaluation procedure implies that constraints have to be defined among the options in order to obtain the respective values of their weighting coefficients [20–22]. In this evaluation, attention will be focused on a number of cases to be analyzed that correspond to the individual priority of every indicator with the other indicators having the same value. In this analysis, the following cases are taken.

3.1.1.1. Case 1: EI > NGC = NGT = INV = NGD. Case 1 (Fig. 2) is designed with priority given to the Environmental Indicator while the other indicators have the same value of weighting coefficient. For this case, it is noticed that priority is obtained for the LNG Terminal Neum and the Gas by Wire options followed by the West Balkan and then the Nabucco options. One characteristic of this case is that the Yamal Gas Route option is at the lowest position in the priority list.

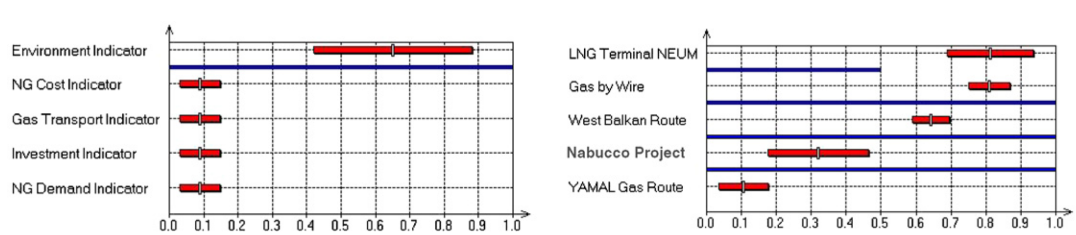

Fig. 2. Weight coefficient and General Index for Case 1.

3.1.1.2. Case 2: NGC > EI = NGT = INV = NGD. Case 2 (Fig. 3) is characterized by priority given to the Natural Gas Cost Indicator. It is noticed that the Gas by Wire, the Nabucco and the West Balkan options have similar priorities. The LNG Terminal Neum option has a slightly lower priority while the Yamal Route option is much lower.

3.1.1.3. Case 3: NGT > EI = NGC = INV = NGD. In Case 3 (Fig. 4), priority is given to the Natural Gas Transport Cost indicator. Here, the West Balkan, the Nabucco and the Gas by Wire options have the highest priority. It can be noticed that the dispersion for some options of this group is smaller than for those of Case 2.

3.1.1.4. Case 4: INV > EI = NGC = NGT = NGD. Case 4 (Fig. 5) is characterized with priority given to the Investment Indicator. The results obtained focus our attention on the Gas by Wire and on the LNG Terminal Neum options, which have substantially higher values of General Index. It should also be mentioned that this case is very probable among all combinations taken into consideration.

3.1.1.5. Case 5: NGD > EI = NGC = NGT = INV. Case 5 (Fig. 6) is designed with priority given to the Natural Gas Demand Indicator. Here, there is very high dispersion of the General Index values for all options. This implies that this situation takes into account very different combi-

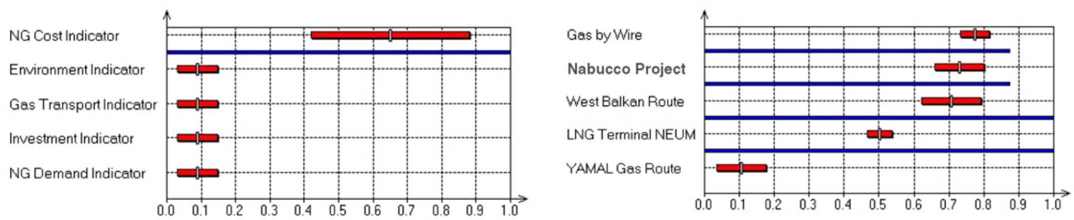

Fig. 3. Weight coefficient and General Index for Case 2.

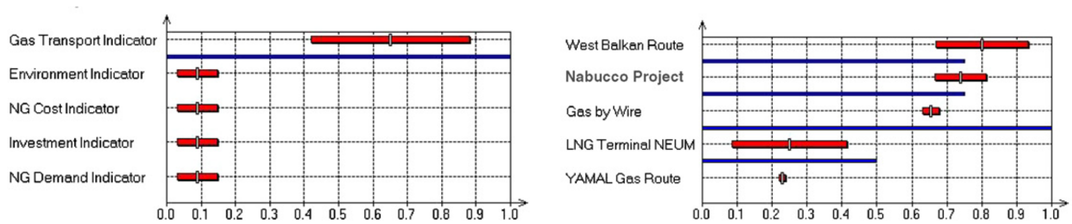

Fig. 4. Weight coefficient and General Index for Case 3.

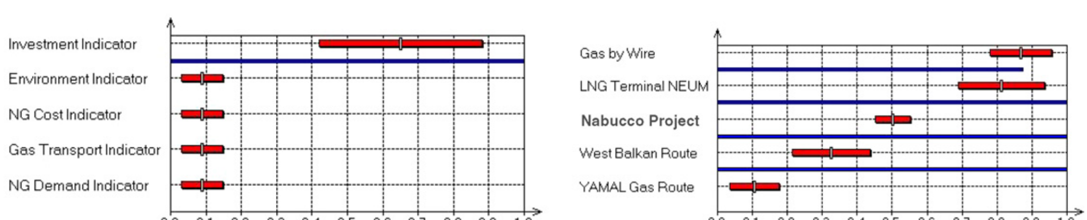

Fig. 5. Weight coefficient and General Index for Case 4.

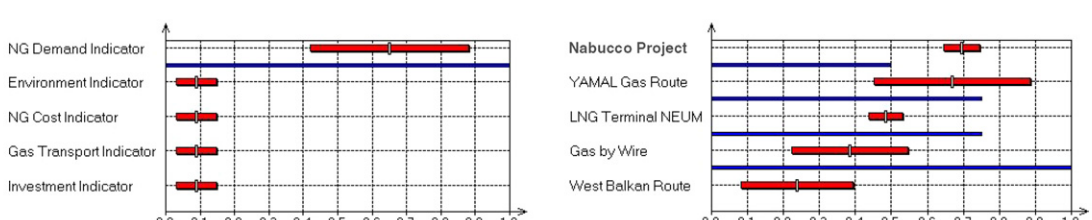

Fig. 6. Weight coefficient and General Index for Case 5.

nations within the set of all combinations being considered in this evaluation.

3.1.2. Group 2

Group 2 cases are aimed to emphasise the role of the cases when internal priorities amongst them are defined by ordinal information that defines the mutual relations of the criteria and the respective indicators. It is obvious that the number of such cases can be very much larger than that of Group 1. The cases are formed by ordering the criteria, always keeping another criterion at the first position. In this group, the results are presented as Cases 6–10.

3.1.2.1. Case 6: EI > NGC > NGT > INV > NGD. Case 6 (Fig. 7) is designed with the aim to give priority to the Environmental Indicator with the other indicators having the priorities shown in Fig. 7. It is of interest to notice that this constraint amongst the indicators leads to marginal differences amongst the Gas by Wire, West Balkan and LNG Terminal Neum. It also becomes obvious that by introducing constraints amongst the indicators by priority gives a smaller dispersion of the weight coefficients.

3.1.2.2. Case 7: NGC > EI > NGT > INV > NGD. Case 7 (Fig. 8) is defined with priority given to the NG Cost Indicator. As for Case 6, the Gas by Wire and the West Balkan options have priority in comparison to the Nabucco Project and the LNG Terminal Neum options. There is also a substantial decrease in the dispersion of the General Index.

3.1.2.3. Case 8: NGT > EI > NGC > INV > NGD. Case 8 (Fig. 9) is characterized with priority given to the Gas Transport Indicator. This case shows that only marginal differences exist compared with Case 7. Again, the West Balkan Route and the Gas by Wire options have priority in comparison with the other options.

3.1.2.4. Case 9: INV > EI > NGC > NGT > NGD. If the Investment Cost Indicator (Fig. 10) has priority compared to the other indicators hierarchically ordered, then the Gas by Wire and LNG Terminal Neum options get marked priority. The West Balkan Route and the Nabucco Project occupy second place on the priority list.

3.1.2.5. Case 10: NGD > EI > NGC > NGT>INV. Finally, in Case 10 (Fig. 11), priority is given to the NG Demand Indicator. As can be noticed, in this case, there is no substantial difference in the General Index amongst the options under consideration. It is shown that if priority is given to the NG Demand and the Environmental

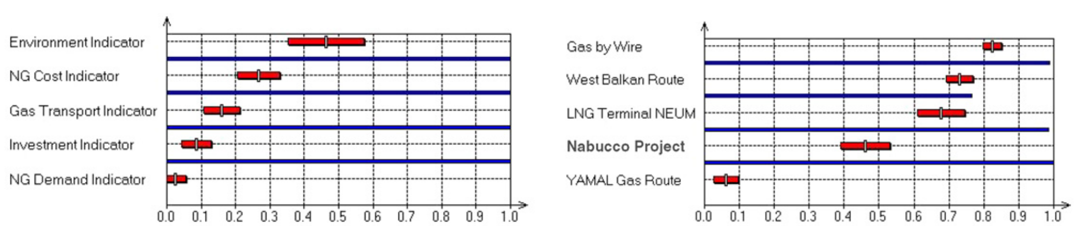

Fig. 7. Weight coefficient and General Index for Case 6.

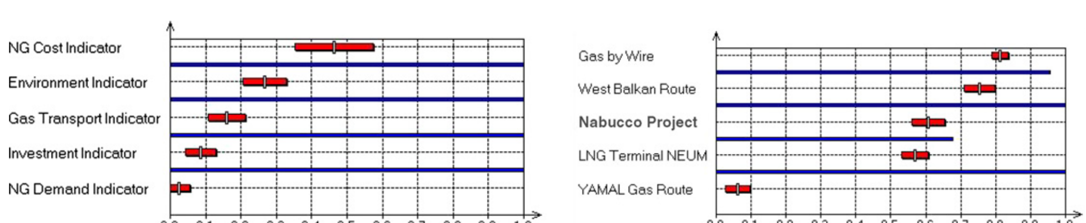

Fig. 8. Weight coefficient and General Index for Case 7.

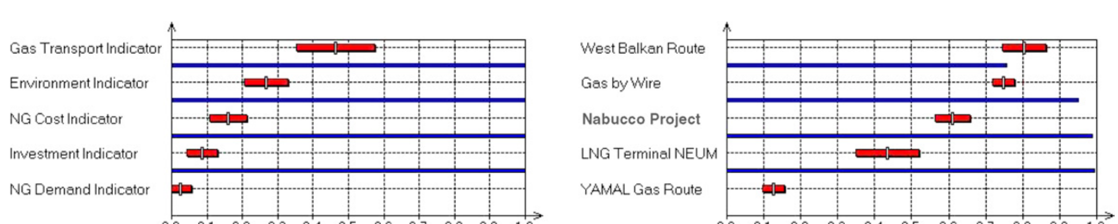

Fig. 9. Weight coefficient and General Index for Case 8.

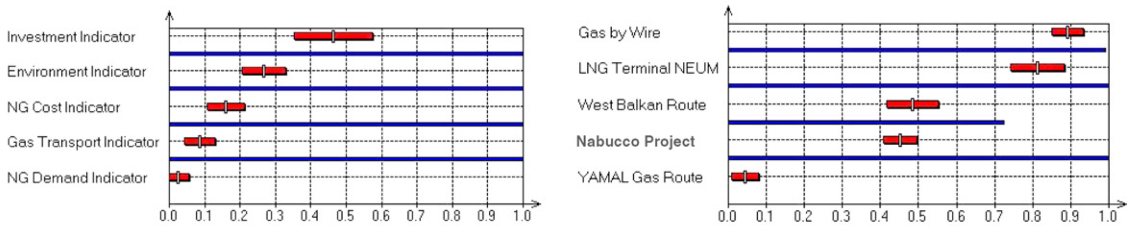

Fig. 10. Weight coefficient and General Index for Case 9.

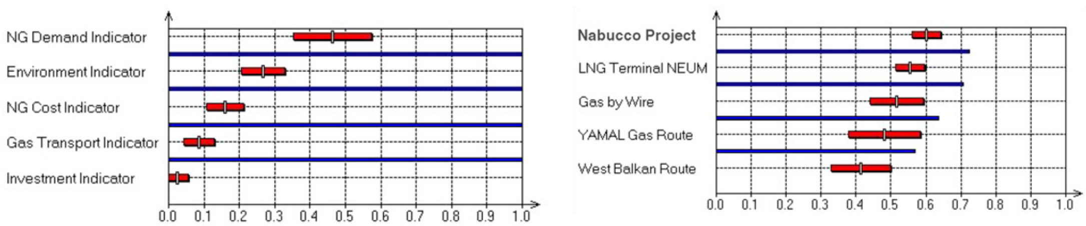

Fig. 11. Weight coefficient and General Index for Case 10.

Indicator, the difference in the General Index is marginal, with a slight advantage for the Nabucco Project.

4. Discussion of the results

Two groups of cases were considered in this analysis. One group (Cases 1–5) was designed with priority given to individual indicators, while the other indicators had the same value, and the second group (Cases 6–10) consisted of cases where the priorities were defined always keeping one criterion in first position, while the priorities of the other criteria were defined by ordinal information defining the mutual relations of the criteria and the respective indicators.

In the fist group, the number of cases analyzed is rather limited and will represent only a partial number of the potential cases amongst the indicator constraints. By assessing all five cases, it is concluded that depending on the constraints imposed amongst the indicators, different rating lists among alternative options are obtained. It can be noticed that Case 1 (EI highly weighted) and Case 4 (INV highly rated) provide essentially the same discrimination between options. The same applies for Case 3 (NGT highly weighted) and Case 5 (NGD highly weighted) where discrimination does not appear to be as good as that using Cases 1 and 4.

The second group comprises cases with hierarchical constraints, with changing priority in constraints in each case. Amongst these cases, priority is obtained for Gas by Wire in Case 6 (EI highly weighted), Case 7 (NG Cost highly rated) and Case 9 (INV highly weighted).

In this analysis, it is assumed that the results obtained for each case have equal importance for the decision making evaluation. In the final rating list based on the summation of values determined by the position of each alternative option, the final Option List Rating can be established. Therefore, the following rating list among options is obtained (Table 3).

Table 3
Option rating

	Option	Rate
1	Gas by Wire	21
2	LNG Terminal Neum	25
3	Nabucco Route	28
4	West Balkan Route	30
5	Yamal Route	41

Even if this type of analysis contains arbitrariness in the evaluation of the priorities among the alternative options, it is noticed that the Gas by Wire option and the LNG Terminal Neum option are the best choices under the constraints used. By increasing the number of cases to be analyzed, a better result for decision making should be obtained. It should also be noticed that, in this type of evaluation, further improvement of the data might lead to higher quality results.

5. Conclusions

This paper is devoted to priority ratings amongst selected alternative options of gas transport systems in Southeast and Central Europe. The evaluation is based on the multi-criteria decision making procedure. The primary goal of this analysis is to use the method based on non-numerical information as the constraint for the design of the options under consideration.

Cases in the first group considered combinations where individual indicators are given priority, while the other indicators have the same weight coefficient. The second group of cases are obtained by hierarchically rated indicators used in the design of constraints amongst the indicators. Even if this analysis is based on a limited number of cases, it is noticed that the priority on the final rating list is the result of the respective relations amongst the criteria under consideration.

It is of interest to notice that the Gas by Wire and the LNG Terminal Neum options are the most attractive solutions obtained through evaluation of the alternative options for the final decision. Obviously, one of the major deficiencies of this analysis is that most data used are derived from the available literature and may not be sufficiently accurate.

References

[1] Haung JO, Poh KL, Ang BW. Decision analysis in energy and environmental modelling. Energy 1995;20:843–55.

[2] Poher SD, Ramachandran M. Application of multi-criteria decision making to sustainable energy planning. Renew Sustain Energy Rev 2004;8:365–81.

[3] Samouilidis J, Mitropoulos C. Energy economy models: a survey. Eur J Oper Res 1982;11(3):222–32.

[4] Meirer P, Mubayi V. Modeling energy–economic interactions in developing countries – a linear programming approach. Eur J Oper Res 1983;13:41–59.

[5] Kavrakoglu I. Multi-objective strategies in power system planning. Eur J Oper Res 1983;12(2):159–70.

[6] Schulz V, Stehfest H. Regional energy supply optimization with multiple objectives. Eur J Oper Res 1984;17:302–12.

[7] Climenco J, editorMulti-criteria analysis. New York: Springer Verlag; 1997.

[8] Gal T, Hanne T, editorsMulti-criteria decision-making: advances in MCDM models, algorithms, theory, and applications. New York: Kluwer Academic Publisher; 1999.

[9] Roy B. Multicriteria methodology to aid the décision. Collection Gestion. Paris: Economica; 1985.

[10] Goicoecheva A, Hansen D, Duckstain L. Introduction to multi objective analysis with engineering and business application. New York: Wiley; 1982.

[11] Brans JP, Vincke Ph, Marechal B. How to select and how to rank projects: the PROMETHEE method. Eur J Oper Res 1986;24:228–38.

[12] Saaty TL. The analytic hierarchy process. New York: McGraw Hill; 1980.

[13] Saaty TL. Derision making for leaders. Pittsburgh: RWS Publications; 1992.

[14] Keeny RL, Raiffa H. Decisions with multiple objectives: preferences and value tradeoffs. New York: Wiley; 1976.

[15] Hovanov Nikolai V, Fedorov Yuri V, Zakharov Viktor V. The making of index number under uncertainty. In: Pykh Y, Haytt DE, Lenz RJM, editors. Advances in sustainable development environmental indices. Oxford, UK: EOLSS Publishers Co.; 1999.

[16] Afgan NH, Carvalho MG, Hovanov N. Indicators for sustainable energy systems. Thermal Science 2005;9(2).

[17] Hovanov N, Kornikov V, Seregin I. Qualitative information processing in DSS ASPID-3W for complex objects estimation under uncertainty. In: Proceedings of the international conference informatics and control, St. Petersburg, Russia; 1997. p. 808–16.

[18] Afgan NH, Carvalho MG. Sustainability assessment method for energy systems. New York: Kluwer Academic Publisher; 2000.

[19] Afgan NH, Carvalho MG. Quality, sustainability and indicators of energy systems. Begell House; 2006.

[20] Afgan NH, Pilavachi PA, Carvalho MG. Multi-criteria evaluation of natural gas resources. Energy Policy 2007;35:704–13.

[21] Pilavachi PA, Roumpeas CP, Minett S, Afgan N. Multi-criteria evaluation for CHP systems. Energy Conserv Manage 2006;47:3519–29.

[22] Zhou Zupeng, Hua Jiang, Liancheng Qin. Life cycle sustainability assessment of fuels. Fuel 2007;86(1–2):256–63.