Energy Economics 36 (2013) 716–728

Contents lists available at SciVerse ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

A PROMETHEE-GDSS for oil and gas pipeline planning in the Caspian Sea basin ☆

Madjid Tavana [a,*], Majid Behzadian [b], Mohsen Pirdashti [c], Hasan Pirdashti [d]

[a] *Business Systems and Analytics Department, Lindback Distinguished Chair of Information Systems and Decision Sciences, La Salle University, Philadelphia, PA 19141, USA*
[b] *Industrial Engineering Department, Faculty of Engineering, MehrAlborz University, Tehran 14136, Iran*
[c] *Chemical Engineering Department, Faculty of Engineering, Shomal University, Amol, 46134, Iran*
[d] *Department of Geography, Faculty of Humanity & Social Science, University of Mazandaran, Babolsar 47415, Iran*

ARTICLE INFO

Article history:
Received 17 August 2012
Received in revised form 31 October 2012
Accepted 21 November 2012
Available online 30 November 2012

JEL classification:
C44
D7
D8
P28

Keywords:
PROMETHEE
GDSS
Delphi
SWOT
Oil and gas pipeline
Caspian Sea

ABSTRACT

The demand for oil and natural gas has severely challenged the world supply. The Caspian Sea basin holds large quantities of both oil and natural gas. Pipelines are needed to transport the oil and natural gas from this landlocked region over long distances within countries and across borders to meet this increasing demand. The evaluation of alternative export routes in the Caspian Sea basin is a complex multicriteria problem with conflicting objectives. We present a Group Decision Support System (GDSS) for the evaluation of alternative pipeline routes in this region. The proposed system decomposes the route selection process into manageable steps. The system combines Strength, Weakness, Opportunity and Threat (SWOT) analysis with the Delphi method to capture the decision makers' (DMs') beliefs. A group Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) model is used to integrate these beliefs with subjective judgments and identify the most attractive pipeline route. The Geometrical Analysis for Interactive Assistance (GAIA) plane is used to further analyze the alternative routes and arrive at a group solution consistent with managerial goals and objectives.

1. Introduction

The oil and natural gas industry is the backbone of the world economy (Balat, 2010). The rapid economic expansion in developed countries coupled with the growing economies has precipitated a steady increase in the demand for oil and natural gas (Bambawale and Sovacool, 2011a, 2011b). According to BP (BP Statistical Review of World Energy, 2011), the demand for all forms of energy grew 5.6% in 2010. The consumption growth accelerated by 3.5% in the OECD (organization for economic co-operation and development) countries (which includes 34 countries including the U.S., U.K., France, Germany, and Japan) while the consumption grew by 7.5% in the non-OECD countries. The vital importance of energy together with the constant increase in demand for oil and gas necessitates the exploration, development and distribution of new sources of energy. The Caspian Sea region's oil and gas potential has attracted the attention of the international oil and gas industry when investment in the region became possible with the breakup of the Soviet Union (Effimoff, 2000; Tsygankova, 2012). The Caspian Sea is the world's largest inland sea and has a significant amount of oil and natural gas reserves (BP Statistical Review of World Energy, 2011). The sea is bordered by five states of Azerbaijan, Kazakhstan, Turkmenistan, Iran and Russia. Most of the proven energy reserves in the region belongs to Kazakhstan and is concentrated in the eastern side of the sea. As shown in Table 1, Azerbaijan possesses both oil and natural gas reserves while Turkmenistan possesses mostly natural gas. Russia and Iran hold inconsequential proven reserves in their respective Caspian sectors.

As shown in Table 2, the proven oil reserves for the Caspian Sea region are estimated at 47.4 billion barrels at the end of 2010 comparable to those in Libya (BP Statistical Review of World Energy, 2011). Natural gas reserves in the Caspian Sea region are even larger than the region's oil reserves. Overall, proven natural gas reserves in the Caspian region are estimated at 11.1 trillion cubic meters at the end of 2010, greater than Saudi Arabia (BP Statistical Review of World Energy, 2011).

The Caspian energy has attracted extensive global policy interest during the past two decades. The intense international focus on the region is driven by its geopolitical significance and its unique landlocked location. The Caspian Sea region is on a major junction

☆ The authors would like to thank the anonymous reviewers and the editor for their insightful comments and suggestions.

* Corresponding author. Tel.: +1 215 951 1129; fax: +1 267 295 2854.
E-mail addresses: tavana@lasalle.edu (M. Tavana), behzadian_ie@yahoo.com (M. Behzadian), pirdashti@shomal.ac.ir (M. Pirdashti), pirdashti614@yahoo.com (H. Pirdashti).
URL: http://tavana.us (M. Tavana).

0140-9883/$ – see front matter
http://dx.doi.org/10.1016/j.eneco.2012.11.023

Table 1
The Caspian oil and natural gas proved reserves—at end 2010[a].

Main producers in the Caspian Sea	Oil reserves (billion barrels)	Gas reserves (trillion cubic meters)
Kazakhstan	39.80	1.80
Azerbaijan	7.00	1.30
Turkmenistan	0.60	8.00

[a] Source: BP Statistical Review of World Energy (2011).

between Europe and Asia and positioned nearby Russia and China. In addition, due to its landlocked location, the Caspian exporters are dependent on other states for moving their energy products. The control of the oil and gas pipelines in the region provides significant influence over the security and policies of the Caspian states. Thus, the recent intense interest in the Caspian region and the battle over the pipeline routes has been more about determining the geostrategic orientation of the region and had little to do with the control of the Caspian states' modest volumes of oil and gas. Delimitation of the sea borders has been a contested issue in the last two decades among the Caspian states. However, legal disputes have not been an obstacle to the production and export of oil and gas (Shaffer, 2010). The major obstacles to the development of new supplies were not related to underground resources but what happens above the ground such as international relations, governmental affairs, and investment in energy and new technological development (Umbach, 2010).

In spite of the potential for the Caspian states to meet the increasing global demand for energy resources, only a few Caspian oil and natural gas export projects have become operational over the last decade (Shaffer, 2010). In this study, a Group Decision Support System (GDSS) is developed to evaluate five possible pipeline routes from the Caspian Sea region for a multinational oil and gas producer. The proposed system combines Delphi method with Strength, Weakness, Opportunity and Threat (SWOT) analysis and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) method in conjunction with the Geometrical Analysis for Interactive Assistance (GAIA) method to capture the DMs' beliefs through a series of intuitive and analytical methods.

This paper is organized into five sections. The next section presents a review of multiple criteria paradigms in the literature. Section 3 details the proposed framework. Section 4 presents the results of a case study and Section 5 sums up our conclusions and future research directions.

2. Literature review

Strategy development and assessment is the process of identifying and evaluating alternatives for utilizing an organization's resources for the purpose of achieving its mission (Li et al., 2002). The process of strategy development requires input from and cooperation of many organizational functions and stakeholders because of the inherent complexities and perceived ambiguities (Eden, 1990; Li et al., 2000; Mintzberg, 1994a, 1994b; Porter, 1987). Strategy development and assessment is widely used for energy planning and decision making (Tavares et al., 2006). Liu et al. (1992) proposed a strategic decision-making model for evaluating the technological and environmental impacts of energy planning and consumption according to a series of socioeconomic, political, environmental, energy and technological factors. Iskin et al. (2012) considered a set of social, technological, environmental and economic factors with an analytic network process to simultaneously consider and systematically integrate a set of factors impacting renewable energy pricing decisions. Bai et al. (2012) proposed a mathematical model to determine an optimal stockpiling path for China's strategic petroleum reserve under different scenarios prioritizing the effects of oil price, risks and elasticity value on inventory size.

The hybrid GDSS proposed in this study is used to identify and evaluate strategies for locating a pipeline to transport oil and gas from the Caspian basin to world markets. Many frameworks have been formulated to identify different forms of (group) decision support. However, these frameworks focus more on the hardware and software, than on the process of decision-making in groups (Van Groenendaal, 2003).

The Delphi method was developed at the RAND Corporation to obtain the most reliable consensus of opinion from a group of knowledgeable individuals about an issue not subject to objective solution (Dalkey and Helmer, 1963). Delphi is a structured group interaction that proceeds through multiple rounds of opinion collection and anonymous feedback. Although the origins of Delphi dates back to early 1950s, the most recognized description of the method was offered by Linstone and Turoff (1975). Fischer (1978), Schmidt (1997), Okoli and Pawloski (2004), and Keeney et al. (2006) have provide excellent reviews of Delphi and its applications.

Each round in Delphi involves a written survey of the participants followed by anonymous feedback to them for each survey question. After seeing the results from the previous round, the participants are asked to reconsider their opinions. Generally, there is a convergence of opinions after three or four rounds, and a stabilized group opinion emerges. This group opinion may reflect agreement, disagreement or a combination of both. The optimum number of participants in a Delphi study depends on the number needed to have a representative pooling of views (Ndour et al., 1992). In this study, Delphi is used to identify the SWOT factors relevant to the oil and gas pipeline route selection process in the Caspian Sea basin.

Since its inception in the early 1950s, SWOT analysis has been used with increasing success in strategic planning tool by both researchers and practitioners (Panagiotou, 2003). The process is used to segregate environmental factors and forces them into internal strengths and weaknesses and external opportunities and threats (Duarte et al., 2006; Valentin, 2001). The SWOT matrix developed by Weihrich (1982) for situational analysis is one of the most important references in the field. Even with its popularity, Novicevic et al. (2004) observe that SWOT is a conceptual framework with limited prescriptive power. Nevertheless, SWOT remains a useful tool for assisting DMs to structure complex and ill-structured problems (Anderson and Vince, 2002; Hitt et al., 2000). In this study, SWOT factors are used in a PROMETHEE method to identify and evaluate alternative pipeline routes for transporting oil and gas from the Caspian basin to world markets.

The PROMETHEE family of outranking methods was first introduced by Brans (1982) in the form of partial ranking of alternatives. Subsequently, the method was extended by Brans and Vincke (1985) to a full ranking approach, which is presently known as PROMETHEE II. A

Table 2
The top world countries with oil and natural gas proved reserves—at end 2010[a].

Oil		Gas	
Country (region)	Oil reserves (billion barrels)	Country (region)	Gas reserves (trillion cubic meters)
Saudi Arabia	264.5	Russian Federation	44.8
Venezuela	211.2	Iran	29.6
Iran	137.0	Qatar	25.3
Iraq	115.0	Caspian Sea region	11.1
Kuwait	101.5	Saudi Arabia	8.0
United Arab Emirates	97.8	US	7.7
Russian Federation	77.4	United Arab Emirates	6.0
Caspian Sea region	47.4	Venezuela	5.5
Libya	46.4	Nigeria	5.3

[a] Source: BP Statistical Review of World Energy (2011).

few years later, several versions of the PROMETHEE methods were developed to help with more complicated decision-making situations (Brans and Mareschal, 2005). PROMETHEE takes into account the amplitude of the deviations between the evaluations of the alternatives within each factor, eliminates the scaling effects completely, identifies the number of incomparabilities, provides information on the conflicting nature of the factors, and offers sensitivity tools to test easily different sets of weights (Brans and Mareschal, 2005). More specifically, the PROMETHEE method deals with ranking a finite number of alternatives based on multiple conflicting factors with inputs from a group of DMs (Macharis et al., 2004). The PROMETHEE methods have been successfully applied to various fields, including environment management (Briggs et al., 1990; Chou et al., 2007; Martin et al., 2003; Morais and De Almeida, 2007; Queiruga et al., 2008), hydrology and water management (Hermans et al., 2007; Pudenz et al., 2002), and energy management (Goletsis et al., 2003; Haralambopoulos and Polatidis, 2003; Hyde et al., 2003; Madlener et al., 2007).

PROMETHEE GDSS, a member of the PROMETHEE family of methods, was developed to provide decision aid to a group of DMs (Macharis et al., 1998). PROMETHEE GDSS is initiated with an identification of the alternatives and criteria. It is followed with an individual evaluation conducted by each DM. Finally a global evaluation is performed by the group to select the best alternative. Several authors have used PROMETHEE GDSS to solve a variety of multi-factor multi-person decision problems (Colson, 2000; Goletsis et al., 2003; Haralambopoulos and Polatidis, 2003; Leyva-López and Fernández-González, 2003; Macharis et al., 1998; Raju et al., 2000). Macharis et al. (1998) and Behzadian et al. (2010) have provided excellent reviews of the PROMETHEE methodologies and their applications.

In this study, we developed a GDSS to enhance the communication among the DMs throughout the Delphi process and SWOT analysis and perform all the necessary computing and graphics for PROMETHEE and GAIA. The proposed system is used to integrate multicriteria modeling into a GDSS. The overall model, based on the PROMETHEE and GAIA concepts, is the core component of the system. The architecture of the GDSS is based on web technology for portability and easy integration. We used a layered approach to develop the proposed system which is comprised of three distinct but interconnected user interface, application and data layers (Fig. 1):

1. User interface layer, comprised of an individual interface and a group interface, incorporates a Language module (all messages the GDSS can accept) and a presentation module (all messages the GDSS can produce).
2. Application layer hosts all the functional modules which implement the proposed hybrid methodology.
3. Data layer stores all the necessary data for decision problem.

An appealing aspect of the PROMETHEE methodology is its ease of use. Another one is the existence of GAIA which supports PROMETHEE in the visual analysis of the results (Brans and Mareschal, 1994). In this study, we enrich the PROMETHEE solution with GAIA analysis to highlight the conflicts, similarities and independencies among the decision factors and the DMs. The graphical representation of the multicriteria problem enables the DM to better understand the available choices and the necessary compromises needed to achieve a better decision outcome. The GAIA plane, a visual interactive module based on the principal component analysis method gives the best possible two-dimensional representation of all the data in a problem, enabling to visualize the conflicts between the performance measures (Behzadian et al., 2010).

3. The proposed framework

The framework outlined below is proposed to select the most attractive alternative pipeline route.

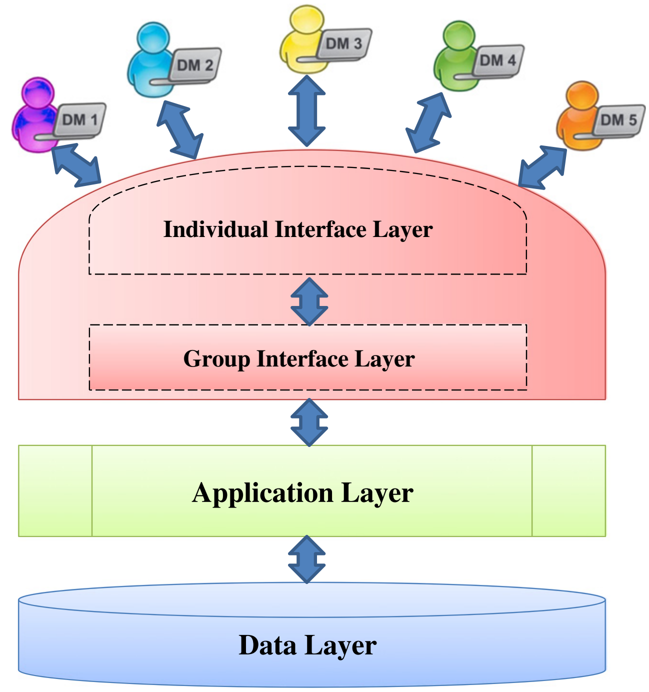


Fig. 1. The GDSS architecture.

3.1. Step 1: Team formation and alternative generation

We begin the process by establishing a decision-making group comprised of m decision makers (DMs), DM_i ($i = 1, \ldots, m$). The DM group use Delphi method and collectively generates a set of alternative pipeline routes, $A = \{a, b, \ldots\}$, and a set of SWOT factors (evaluation criteria), $C = \{c_1, c_2, \ldots, c_n\}$.

3.2. Step 2: SWOT analysis

This step involves a series of Delphi rounds to develop a set of relevant factors for use in the SWOT analysis. In the first Delphi round, the DMs are asked to individually consider the economic, political, legal, environmental, cultural and social, and geographical and technological issues and compile a set of factors considered to be important in the pipeline decision. These personal lists are then provided to the facilitators anonymously. The facilitators combine all of these factors into a comprehensive list. In the follow-up rounds, this list is shared with all the DMs and they are asked to consider this feedback and then revise and resubmit their initial individual list. This process is repeated until the DMs agree that they could no longer reduce the number of factors in the list. The DMs then collectively classify all the factors into economic, political, legal, environmental, cultural and social, and geographical and technological categories. The DMs then collectively classify each factor as either external or internal and categorize external factors into opportunities and threats and internal factors into strengths and weaknesses.

The procedure in this step is used to assign the weight to the factors for individual ranking and to the DMs for global ranking. The DMs and the facilitators also collectively assign a voting weight to each group member as the proportion of the total weight (where the total weight is normalized to 1) according to some pre-specified rule(s). In contrast, the group may give equal weights where appropriate. Let us assume that $w_i = \{w_1, w_2, \ldots, w_m\}$ is the weight vector of the DMs, such that $w_i \geq 0$, $i = 1, \ldots, m$, and $\sum_{i=1}^{m} w_i = 1$. Since each factor Cj may not be equally weighted, we let $\hat{w}_j =$

$\{\hat{w}_1, \hat{w}_2, \ldots, \hat{w}_m\}$ be the weight vector of the factors, such that $\hat{w}_j \geq 0$, $i = 1, \ldots, m$, and $\sum_{j=1}^{n} \hat{w}_j = 1$. It should be noted that each DM assigns an individual weight to each factor and the weight vectors of the factors for each DM may be different from the other DMs.

3.3. Step 3: Individual ranking and analysis

The individual evaluation and GAIA analysis for each DM are carried out in this step. The difference between any two potential alternatives can be determined as follows:

$$d_{ij}(a,b) = g_{ij}(a) - g_{ij}(b), i = 1, \ldots, m, j = 1, \ldots, n, \forall a, b \in A \tag{1}$$

where $d_{ij}(a,b)$ denotes the difference between the evaluation factors on alternatives a and b for DM$_i$ with respect to factor j. A represents the finite set of possible alternatives available to DM$_i$, and $g_{ij}(a)$ represents the evaluation factors used to evaluate alternative a on factor j by DM$_i$. For instance, the function $g_{ij}(.)$ can represent the cost of choosing alternative a. The preference between 2 alternatives for each factor can be defined as:

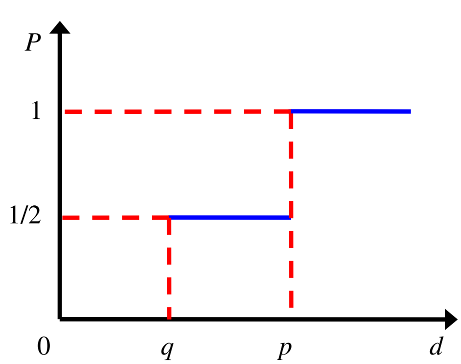
$$P_j(a,b) = F_j\left[d_{ij}(a,b)\right], i = 1, \ldots, m, j = 1, \ldots, n \tag{2}$$

where $P_j(a,b) \in [0,1]$ denotes the preference of alternative a to alternative b for DM$_i$ on factor j, and $F_j(.)$ represents the type of preference function used for factor j by DM$_i$. We adopt the six possible choices of the preference function postulated by Brans and Vincke (1985) to assist the DMs. For example, if DM$_i$ selects a type 4 function presented in Fig. 2, then, DM$_i$ is required to specify the threshold values of p (strict preference) and q (indifference) such that DM$_i$ is fully satisfied and totally indifferent. Similarly, if the factor is set on an interval scale, DM$_i$ may choose a type 5 function presented in Fig. 3 to represent his/her assessment.

In this step, we compute an aggregate preference index for each factor as follows:

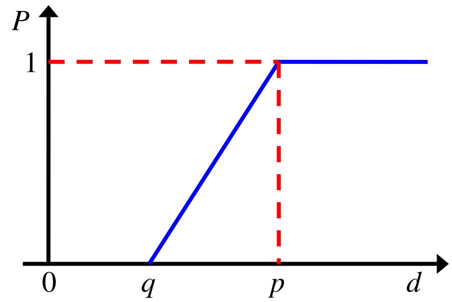
$$\pi(a,b) = \sum_{j=1}^{k} P_j(a,b)\hat{w}_j \quad \forall a, b \in A \tag{3}$$

where $\pi(a,b)$ of a over b (from zero to one) is defined as the weighted sum of $P_j(a,b)$ for factor j, and $\hat{w}_j$ is the weight associated with factor j. In addition, $\pi(a,b)$ expresses the degree to which a is preferred to b for all factors. Alternative a is facing $(n-1)$ other alternatives in A.



$$P(d) = \begin{cases} 0 & d \leq q \\ 1/2 & q < d \leq p \\ 1 & d > p \end{cases} \qquad p, q$$

Fig. 2. The type 4 preference function (best suited for qualitative factors) used for individual ranking.



$$P(d) = \begin{cases} 0 & d \leq q \\ (d-q)/(p-q) & q < d \leq p \\ 1 & d > p \end{cases} \qquad d, p$$

Fig. 3. The type 5 preference function used for global ranking.

Therefore:

$$\begin{aligned} \phi^+(a) &= \frac{1}{n-1}\sum_{x \in A} \pi(a,x) \\ \phi^-(a) &= \frac{1}{n-1}\sum_{x \in A} \pi(x,a) \end{aligned} \tag{4}$$

where $\phi^+(a)$ and $\phi^-(a)$ denote the positive and negative outranking flows for alternative a, respectively. In other words, $\phi^+(a)$ expresses how alternative a is outranking all other $(n-1)$ alternatives, while $\phi^-(a)$ expresses how alternative a is outranked by all other alternatives.

In this step, we also compute the net outranking flow and complete the ranking of the potential alternatives as follows:

$$\phi(a) = \phi^+(a) - \phi^-(a) \tag{5}$$

where $\phi(a)$ denotes the net outranking flow of alternative a. The final ranking is obtained based on the principle that the higher the net flow is, the more attractive the alternative is.

3.4. Step 4: Global ranking and synthesis

The global evaluation and GAIA analysis for group decision-making are carried out so that all the DMs are advised on the potential conflicts. The last step of the process is summarized as follows:

$$P_i(a,b) = F_i[\phi_i(a) - \phi_i(b)] \quad i = 1, \ldots, m \tag{6}$$

where $P_i(a,b)$ denotes the preference of alternative a to alternative b for DM$_i$.

$$\pi_{gdss}(a,b) = \sum_{i=1}^{m} P_i(a,b) w_i \tag{7}$$

where $\pi_{gdss}(a,b)$ is defined as the weighted sum of $P_i(a,b)$ for all DMs, with w_i as the weight for DM$_i$. The PROMETHEE partial and complete rankings are obtained from the following equations:

$$\phi^+{}_{gdss}(a) = \frac{1}{m-1}\sum_{x \in A} \pi_{gdss}(a,x) \text{ and } \phi^-{}_{gdss}(a) = \frac{1}{m-1}\sum_{x \in A} \pi_{gdss}(x,a) \tag{8}$$

$$\phi_{gdss}(a) = \phi_{gdss}{}^+(a) - \phi_{gdss}{}^-(a) \tag{9}$$

where $\phi_{gdss}{}^+(a)$, $\phi_{gdss}{}^-(a)$ and $\phi_{gdss}(a)$ denote the positive, negative, and net outranking flows for alternative a, respectively.

Fig. 4. The alternative transportation routes and the main oil and gas extraction zones.

4. Case study

This study was conducted for the Horizon Oil Company,[1] a multinational oil and natural gas producer. The mission of the company is to explore, develop, produce and market crude oil and natural gas. Horizon established a group of experts to collect and synthesize information from many domains and evaluate several alternative routes for transporting Caspian oil and gas to the world energy markets. Group decision-making is an effective way to overcome judgment uncertainty in organizations due to human fallibility (Koh, 1994). Maier (2010) summarizes the virtues of group decision-making as follows: first, if every group member exerts effort to become informed, groups can gather more information than individual members. Better information can lead to better decisions. Second, if all group members have the same information, they may not reach the same conclusion since group members typically have different backgrounds and experiences. Third, if some information is erroneous, a group can pool signals and reduce uncertainty. Fourth, groups provide an insurance against extreme preferences of individual DMs. The framework proposed in this study was used to evaluate alternative pipeline routes in the Caspian Sea basin.

4.1. Step 1: Team formation and alternative generation

Five highly educated senior managers were appointed by the chief executive officer of Horizon to participate in this study. Three managers held graduate degrees in engineering, one held a graduate degree in economics, and one held a graduate degree in management. Although the members of the group were educated, their managerial judgment and intuition were limited by their background and experience. Nevertheless, all five group members were veteran mangers with 15–43 years of experience in the oil and gas industry. The fact that the group members held different kinds of knowledge made it more likely that all aspects of the decision will come under consideration. In addition, the group also relied on 27 researchers and experts at Horizon who assisted the group in conducting research interviews and collecting data over the course of 2 years from different stakeholders involved in oil and natural gas exploration, production, transmission, and distribution. The key duties and responsibilities of the group at Horizon included:

- Identifying and selecting the most preferable route for transporting Caspian oil and gas.
- Overseeing all phases of the evaluation process.
- Resolving conflicts as they arise.
- Developing an action plan for the selected route.
- Obtaining the approval of the top management in the implementation of the action plan.

The alternative oil and gas pipeline route generation began with the participants meeting to discuss the alternative routes proposed by the team of 27 researchers and experts at Horizon who had collected data and conducted feasibility study for the following nine potential routes in the Caspian Sea region: Western route (W), Northern route (N), Southern route (S), Eastern route (E), Southeastern route (SE), Northwestern route (via Azerbaijan, Russia and Black sea) (NW), Western route (via Azerbaijan, Armenia and Turkey) (W2), Southeastern route (via Iran, Afghanistan and Pakistan) (SE2), and Eastern route (via Kazakhstan, Uzbekistan, Tajikistan and Kyrgyzstan) (E2).

The five senior managers and the team of 27 researchers then worked on identifying those alternative routes that could be eliminated from further consideration through logical dominance. They agreed to use the following rule for dominance: if alternative route X is better than alternative route Y on some objectives and no worse than Y on

[1] The name of the company and some details of the study have been changed to protect the anonymity of the company and the security of strategy.

Table 3
The environmental classification of the factors.

Factor code	Factor description	SWOT category
(a)		
ECN01	Financial support of the international community	Opportunity
ECN02	Availability of investment tax credits for oil and gas explorations in the region countries	Opportunity
ECN03	High ROI potentials	Opportunity
ECN04	Financial support of the region/pipeline countries for oil and gas explorations	Opportunity
ECN05	Availability of cheap labor in the region/pipeline countries	Opportunity
ECN06	High level of export in the region/pipeline countries	Opportunity
ECN07	Potential for high and stable energy demand in the region/pipeline countries	Opportunity
ECN08	High level of GDP in the region/pipeline countries	Opportunity
ECN09	High tax rate in the region/pipeline countries	Threat
ECN10	High cost of building and maintaining pipelines in the region/pipeline countries	Threat
ECN11	High level of tariffs and commissions in the region/pipeline countries	Threat
ECN12	High cost of oil & gas transportation and transfer in the region/pipeline countries	Threat
ECN13	High oil and gas drilling & exploration expenses in the region/pipeline countries	Threat
ECN14	Negative effect of pipelines on other industries such as tourism and fishing	Threat
ECN15	Economic dependency of the region/pipeline countries to other countries	Threat
ECN16	Investment security in the region/pipeline countries	Strength
ECN17	Qualified and productive labor force in the region/pipeline countries	Strength
ECN18	Economic stability of the region/pipeline countries	Strength
ECN19	High current oil and gas supply	Strength
ECN20	Low non-oil and gas import/export level in the region/pipeline countries	Weakness
ECN21	Poor oil and gas quality	Weakness
ECN22	Poor forecast for oil and gas supply	Weakness
POL01	Political support of the neighboring countries for the project	Opportunity
POL02	Political support of the international community for the project	Opportunity
POL03	Possibility of Russian control of the pipeline	Threat
POL04	Danger of terrorism in the region/pipeline countries	Threat
POL05	Nuclear proliferation initiatives in the region/pipeline countries	Threat
POL06	Foreign oil and gas dependency of the region/pipeline countries	Threat
POL07	Political stability of the region/pipeline countries	Strength
POL08	Poor security in the region/pipeline countries	Weakness
POL09	Military instability of the region/pipeline countries	Weakness
LEG01	Oil and gas reserve ownership disputes in the region/pipeline countries	Threat
LEG02	Availability & stability of insurance industry in the region/pipeline countries	Strength
LEG03	Strict import/export laws and regulations in the region/pipeline countries	Weakness
LEG04	Strict foreign investment rules and regulations in the region/pipeline countries	Weakness
(b)		
ENI01	Pollution of the sea surface	Threat
ENI02	Pollution of the sea bottom	Threat
ENI03	Pollution of the beaches	Threat
ENI04	Pollution of the water sources	Threat
ENI05	Pollution of the water destinations	Threat
ENI06	Pollution of the rivers and water canals	Threat
ENI07	Pollution caused by nuclear activities	Threat
ENI08	Availability of underground water sources along the route	Threat
TEC01	Ability to maintain and repair current pipelines	Opportunity
TEC02	Ability to expand current pipelines	Opportunity
TEC03	Ability to convert natural gas to liquid gas	Opportunity
TEC04	Adequacy of technologically advanced oil and gas tankers	Strength
TEC05	Adequacy of technologically advanced oil and gas trucks	Strength
TEC06	Adequacy of the oil and gas refineries	Strength
TEC07	Adequacy of the railroad infrastructure	Strength
TEC08	Lack of scientific and technological foundation of the society	Weakness
TEC09	Poor oil and gas transportation infrastructure	Weakness
TEC10	Lack of roads with proper surface and foundation	Weakness
TEC11	Insufficient number of ports for oil and gas transportation	Weakness
CUL01	Common race in the region/pipeline countries	Strength
CUL02	Common culture and customs in the region/pipeline countries	Strength
CUL03	Common national identity in the region/pipeline countries	Strength
CUL04	Common history in the region/pipeline countries	Strength
CUL05	Language diversity in the region/pipeline countries	Weakness
CUL06	Religion diversity in the region/pipeline countries	Weakness
CUL07	Diversity of religious sects in the region/pipeline countries	Weakness
SOC01	Open society	Opportunity
SOC02	Availability of jobs and public assistance programs	Opportunity
SOC03	Educated and trained workers	Opportunity
SOC04	Familiarity of the society with oil and gas industries	Strength
SOC05	Traffic obstacles	Weakness
GEO01	Accessibility to open sea and oceans	Opportunity
GEO02	Suitable beaches with calm waves	Opportunity
GEO03	Shorter distance	Opportunity
GEO04	Hilly and mountainous terrain	Threat
GEO05	Active Earthquake region	Threat
GEO06	High temperature and humidity problems	Threat

(continued on next page)

Table 3 (*continued*)

Factor code	Factor description	SWOT category
GEO07	Low temperature and icy conditions	Threat
GEO08	Desert terrain	Threat
GEO09	Swampy terrain	Threat
GEO10	Offshore distance	Threat
GEO11	Accessibility to straits for passage	Threat
GEO12	Accessibility and availability of oil and gas reserves in the region	Strength
GEO13	Poor soil condition and quality	Weakness

all other objectives, Y can be eliminated from consideration. In such cases, Y is said to be logically dominated by X (Hammond et al., 1998). Following this agreement, the senior managers and the expert researchers participated in several rounds of Delphi and discussed the advantages and disadvantages of each alternative route. In each round of Delphi, the senior managers and the experts evaluated the alternative routes and after each round the two facilitators provided an anonymous summary of the group's judgments from the previous round as well as the reasons they provided for their judgments. The participants were then encouraged to revise their earlier judgments in light of the responses of other members of the group. In the first round of Delphi, the northern route (N) dominated the northwestern route (via Azerbaijan, Russia and Black sea) (NW) (N > NW) mainly because of the war in Georgia which posed some risks associated with the NW alternative. In round 2, the western route (W) dominated the western route (via Azerbaijan, Armenia and Turkey) (W2) (W > W2) mainly because of the strained Armenian–Turkish relations over a number of historical and political issues including the Nagarno–Karabakh War. In the third round of Delphi, the southern route dominated the southeastern route (S > SE2) and in the fourth and final round, the eastern route dominated the eastern route via Kazakhstan, Uzbekistan, Tajikistan and Kyrgyzstan (E > E2) because of ethnic conflict between these countries. Consequently, the NW, W2, SE2 and E2 routes were eliminated from further consideration and a consensus emerged to include the W, N, S, E and SE routes in the subsequent steps of the evaluation process. A detailed mathematical description of the dominance concept is presented in Appendix 1. As for the viability of the five alternative routes, the initial route selection came from Horizon Company and the research team supporting the decision-making process. Nevertheless, these five alternatives are widely proposed or discussed in the literature on oil and gas pipeline planning in the Caspian Sea basin as shown below:

- Western Route (W): Akdemir (2011, p. 73), Babali (2009, p. 1300), Balat (2010, p. 1999), Bilgin (2007, p. 6384), Guliyev and Akhrarkhodjaeva (2009, p. 3174), Mavrakis et al. (2006, p. 1675), Pasquarè et al. (2011, p. 1774), Shaffer (2010, p. 7211) and Sovacool (2011, p. 611).
- Northern Route (N): Newnham (2011, p.137), SÖderbergh et al. (2010, p. 7830) and Stegen (2011, p. 6508).
- Southern Route (S): Akdemir (2011, p. 73), Babali (2009, p. 1300), Bilgin (2009, p. 4488), Kaiser and Pulsipher (2007, p. 1309) and Kakachia (2011, p. 18).
- Eastern Route (E): Akdemir (2011, p. 73), Babali (2009, p. 1300) and Shaffer (2010, p. 7211).
- Southeastern Route (SE): Akdemir (2011, p. 73) and Babali (2009, p. 1300).

Fig. 4 presents the five alternative transportation routes and the main extraction zones for oil and gas in the Caspian Sea region considered in this study.

Horizon intended to use four general zones shown in Fig. 4 for oil and gas extraction. The plan was to use separate but parallel oil and gas pipelines, similar to the parallel Baku–Tbilisi–Ceyhan oil pipeline and the Baku–Tbilisi–Erzerum South Caucasian natural gas pipeline, traversing the same route through the Republic of Georgia (Pasquarè et al., 2011).

4.2. Step 2: SWOT analysis

In this step, the DMs began their discussion of the issues relevant to selecting a pipeline route. However, since the DMs were geographically dispersed throughout the region, video conferencing technology was used to facilitate these discussions. Based on these discussions, the DMs collectively decided to consider the following issues when identifying the relevant factors for the SWOT analysis.

- Economic Issues—Building an oil or gas pipeline is fundamentally a business proposition. Therefore, return on investment (ROI) is a primary decision variable. While ROI is a principal factor in the selection of a pipeline route, it is affected by other factors including cultural, environmental, geographical, legal, political, social and technological issues.
- Political Issues—During the Soviet era, the Caspian region was dominated by the USSR with Moscow controlling regional activities including energy exploration, development and transit. The disintegration of the Soviet Union has fundamentally changed the geopolitical conditions around the Caspian basin. New regional and global actors have emerged asserting their own particular interests. The DMS identified three primary interest groups: the Caspian basin states, the transit countries, and global and regional powers.
- Legal Issues—A large portion of the oil and gas reserves in the Caspian basin is under the seabed. The question of ownership of these resources is disputed and debated by the Caspian littoral states. One of the main problems is the lack of law and law enforcement to define and protect the interests of littoral states.
- Environmental Issues—Economic activity in the Caspian region is fundamentally linked to energy exploration, development and export. The oil and gas industry has been the cause of severe air pollution as well as soil and water contamination. The problems began in the Soviet period when the resources were exploited using environmentally unsound practices. After the collapse of the Soviet Union, the situation became worse because of the lack of cooperation among the Caspian states. Furthermore, the pollutants are accumulating because they are trapped within this land-locked basin. This exacerbates the threat to farming, fishing and the health of the human population.
- Cultural and Social Issues—The Caspian Sea basin is located at the fault line of three clashing civilizations. It is in this region that the Russian Orthodox, Islamic and Hindu world views confront each other resulting in a diversity of customs, languages and religions. These cultures frequently spawn closed societies that resist change and resent outsiders. Consequently, any project as massive and geographically lengthy as a pipeline could transit regions occupied by groups such as these and would likely meet aggressive opposition.
- Geographical and Technological Issues—Much of the Caspian basin energy reserves are located under the seabed or far from potential markets in relatively remote Turkmenistan, Kazakhstan and Uzbekistan. The geographical location of these reserves makes transport a major problem. The Caspian is landlocked so shipping directly by tanker is not possible. All export of energy resources from the Caspian states involves extensive pipelines. One of the pipeline routes is proposed to transit the Caspian seabed. Constructing this pipeline would require bringing highly specialized underwater excavating equipment into the region. Transporting this massive machinery overland would be

Table 4
The overall importance weight of the factors.

Factor code	Factor weights					
	DM 1	DM 2	DM 3	DM4	DM 5	Overall
(a)						
ECN01	0.2	0.2	0.2	0.1	0.1	0.16
ECN02	0.1	0.1	0.1	0.1	0.1	0.10
ECN03	0.1	0.1	0.1	0.1	0.1	0.10
ECN04	0.2	0.1	0.1	0.1	0.1	0.12
ECN05	0.0	0.1	0.1	0.0	0.1	0.06
ECN06	0.1	0.1	0.1	0.1	0.1	0.10
ECN07	0.1	0.2	0.1	0.2	0.2	0.16
ECN08	0.1	0.1	0.2	0.2	0.2	0.16
ECN09	0.1	0.1	0.0	0.2	0.1	0.10
ECN10	0.2	0.2	0.2	0.2	0.3	0.22
ECN11	0.1	0.1	0.1	0.1	0.1	0.10
ECN12	0.2	0.2	0.2	0.2	0.3	0.22
ECN13	0.2	0.1	0.2	0.1	0.2	0.16
ECN14	0.1	0.2	0.1	0.1	0.1	0.12
ECN15	0.2	0.1	0.1	0.1	0.0	0.10
ECN16	0.1	0.2	0.2	0.1	0.1	0.14
ECN17	0.1	0.1	0.0	0.1	0.1	0.08
ECN18	0.1	0.2	0.2	0.1	0.2	0.16
ECN19	0.2	0.1	0.2	0.2	0.2	0.18
ECN20	0.1	0.1	0.0	0.1	0.2	0.10
ECN21	0.2	0.1	0.1	0.2	0.1	0.14
ECN22	0.2	0.0	0.2	0.2	0.1	0.14
POL01	0.5	0.4	0.4	0.4	0.4	0.42
POL02	0.6	0.7	0.6	0.7	0.7	0.66
POL03	0.2	0.1	0.1	0.2	0.0	0.12
POL04	0.6	0.1	0.9	0.6	0.8	0.60
POL05	0.1	0.0	0.0	0.1	0.0	0.04
POL06	0.2	0.1	0.0	0.1	0.1	0.10
POL07	0.4	0.4	0.4	0.5	0.4	0.42
POL08	0.4	0.4	0.4	0.3	0.4	0.38
POL09	0.3	0.3	0.2	0.3	0.2	0.26
LEG01	1.0	1.0	1.0	1.0	1.0	1.00
LEG02	0.3	0.3	0.3	0.3	0.3	0.30
LEG03	0.3	0.4	0.3	0.3	0.4	0.34
LEG04	0.4	0.4	0.4	0.5	0.4	0.42
(b)						
ENI01	0.2	0.1	0.0	0.2	0.1	0.12
ENI02	0.1	0.1	0.1	0.1	0.1	0.10
ENI03	0.1	0.0	0.2	0.1	0.1	0.10
ENI04	0.1	0.1	0.1	0.2	0.1	0.12
ENI05	0.1	0.1	0.1	0.1	0.2	0.12
ENI06	0.2	0.1	0.1	0.2	0.1	0.14
ENI07	0.1	0.1	0.0	0.1	0.1	0.08
ENI08	0.1	0.1	0.2	0.2	0.2	0.16
TEC01	0.5	0.5	0.5	0.5	0.5	0.50
TEC02	0.4	0.5	0.5	0.4	0.4	0.44
TEC03	0.2	0.1	0.0	0.1	0.1	0.10
TEC04	0.1	0.0	0.0	0.1	0.1	0.06
TEC05	0.1	0.0	0.1	0.1	0.1	0.08
TEC06	0.1	0.1	0.2	0.1	0.1	0.12
TEC07	0.1	0.0	0.0	0.1	0.1	0.06
TEC08	0.1	0.2	0.2	0.1	0.2	0.16
TEC09	0.3	0.3	0.3	0.3	0.3	0.30
TEC10	0.1	0.1	0.0	0.1	0.1	0.08
TEC11	0.1	0.2	0.1	0.0	0.1	0.10
CUL01	0.2	0.3	0.1	0.0	0.1	0.14
CUL02	0.1	0.1	0.1	0.0	0.1	0.08
CUL03	0.1	0.1	0.1	0.1	0.0	0.08
CUL04	0.1	0.1	0.0	0.0	0.1	0.06
CUL05	0.3	0.3	0.3	0.3	0.3	0.30
CUL06	0.2	0.1	0.0	0.2	0.1	0.12
CUL07	0.2	0.1	0.2	0.2	0.2	0.18
SOC01	0.4	0.4	0.5	0.5	0.3	0.42
SOC02	0.3	0.4	0.3	0.3	0.4	0.34
SOC03	0.3	0.4	0.2	0.2	0.4	0.30
SCC04	0.6	0.6	0.5	0.6	0.6	0.58
SOC05	0.4	0.5	0.5	0.4	0.5	0.46
GEO01	0.2	0.1	0.2	0.2	0.2	0.18
GEO02	0.2	0.1	0.1	0.1	0.0	0.10
GEO03	0.7	0.8	0.7	0.7	0.9	0.76
GEO04	0.2	0.1	0.2	0.2	0.2	0.18
GEO05	0.1	0.1	0.1	0.2	0.1	0.12

Table 4 (*continued*)

Factor code	Factor weights					
	DM 1	DM 2	DM 3	DM4	DM 5	Overall
(b)						
GEO06	0.1	0.1	0.0	0.1	0.1	0.08
GEO07	0.1	0.2	0.1	0.1	0.1	0.12
GEO08	0.1	0.1	0.0	0.1	0.1	0.08
GEO09	0.1	0.1	0.0	0.1	0.1	0.08
GEO10	0.1	0.1	0.2	0.1	0.2	0.14
GEO11	0.1	0.2	0.1	0.1	0.0	0.10
GEO12	0.6	0.6	0.7	0.8	0.9	0.72
GEO13	0.4	0.4	0.3	0.3	0.2	0.32

difficult, costly and risky. Other proposed routes cross very difficult topography. Land routes to the east, south and west all encounter mountainous terrain at some point. They also confront extreme meteorological conditions that are challenging for people, equipment and the pipeline.

Next, a series of Delphi rounds were used to identify the relevant factors for SWOT analysis. In the first Delphi round, the DMs were asked individually to consider the economic, political, legal, environmental, cultural and social, and geographical and technological issues discussed in Step 2 and to compile a set of factors considered to be important in the pipeline decision. These personal lists were provided to the facilitators anonymously. Then, the facilitators combined all of these factors into a list with 478 factors.

In round 2, this list was shared with all the DMs. They were asked to consider this feedback and then revise and resubmit their initial individual list. The facilitators combined all of these factors into a new list with 242 factors. Again in round 3, the synthesized list of factors from round 2 was shared with all the DMs, and they were asked to revise and resubmit their individual list from round 2. The facilitators then combined all of these factors into another new list with 112 factors. These Delphi rounds were repeated three more times. In round 4, the facilitators synthesized a list of 79 factors. At this point, the DMs agreed that they could not make significant changes to the list. Consequently, a decision was made to use the 79 factors presented in Table 3(a) and (b) in the subsequent steps.

The DMs then collectively classified the 79 factors developed in Step 3 into economic, political, legal, environmental, cultural and social, and geographical and technological categories. While 22 factors were identified as economic concerns, only four factors were perceived as legal issues. Next the DMs collectively classified each factor as either *external* or *internal*. Next, the DMs collectively categorized external factors into *opportunities* and *threats* and internal factors into *strengths* and *weaknesses*. Of the 79 factors presented in Table 3, 47 were classified as external and 32 were categorized as internal. Within the external factors, 19 were perceived as opportunities and 28 as threats. Within the internal factors, 16 were identified as strengths and 16 as weaknesses. The balance of factors between external and internal and threats and opportunities suggests a defensive position in reaction to external threats rather than an offensive orientation in the SWOT analysis.

In a follow-up questionnaire, the participants were asked to score the factors in each category on a scale from 0 to 1, with a 0.1 increment; where a score of 0 represents non-importance and a score of 1 indicates extreme importance. Table 4(a) and (b) presents the importance weight assigned by each DM along with an average for the five The DMs then collectively classified the 79 factors into economic, political, legal, environmental, cultural and social, and geographical and technological categories. While 22 factors were identified as economic concerns, only four factors were perceived as legal issues.

“Shorter distance” (GEO03), “Political support of the international community for the project” (POL02), and “Ability to maintain and

Table 5
The key factors and their overall weights.

SWOT classification	Factor code	Factor weights					Overall weight
		DM 1	DM 2	DM 3	DM4	DM 5	
Opportunities	POL01	0.5	0.4	0.4	0.4	0.4	0.42
	POL02	0.6	0.7	0.6	0.7	0.7	0.66
	TEC01	0.5	0.5	0.5	0.5	0.5	0.50
	TEC02	0.4	0.5	0.5	0.4	0.4	0.44
	SOC01	0.4	0.4	0.5	0.5	0.3	0.42
	SOC02	0.3	0.4	0.3	0.3	0.4	0.34
	SOC03	0.3	0.4	0.2	0.2	0.4	0.30
	GEO003	0.7	0.8	0.7	0.7	0.9	0.76
Strengths	POL07	0.4	0.4	0.4	0.5	0.4	0.42
	LEG02	0.3	0.3	0.3	0.3	0.3	0.30
	SCC04	0.6	0.6	0.5	0.6	0.6	0.58
	GEO12	0.6	0.6	0.7	0.8	0.9	0.72
Threats	ECN10	0.2	0.2	0.2	0.2	0.3	0.22
	ECN12	0.2	0.2	0.2	0.2	0.3	0.22
	POL04	0.6	0.1	0.9	0.6	0.8	0.60
	LEG01	1.0	1.0	1.0	1.0	1.0	1.00
Weaknesses	POL08	0.4	0.4	0.4	0.3	0.4	0.38
	POL09	0.3	0.3	0.2	0.3	0.2	0.26
	LEG03	0.3	0.4	0.3	0.3	0.4	0.34
	LEG04	0.4	0.4	0.4	0.5	0.4	0.42
	TEC09	0.3	0.3	0.3	0.3	0.3	0.30
	CUL05	0.3	0.3	0.3	0.3	0.3	0.30
	SOC05	0.4	0.5	0.5	0.4	0.5	0.46
	GEO13	0.4	0.4	0.3	0.3	0.2	0.32

repair current pipelines" (TEC01) were perceived as leading opportunities by the DMs. In contrast, the group considered "Oil and gas reserve ownership disputes in the region/pipeline countries" (LEG01) and "Danger of terrorism in the region/pipeline countries" (POL04) as the primary potential threats. While the highest rated strength was "Accessibility and availability of oil and gas reserves in the region/pipeline countries" (GEO12), and "Traffic obstacles" (SOC05) was seen as the greatest weakness.

Next, the DMs decided to eliminate those factors that they considered to be relatively unimportant. The DMs agreed to use a threshold of 0.2 out of a possible 1.0. Eight opportunities, four threats, eight weaknesses and four strengths had a weight of 0.2 or greater. This resulted in a more manageable number of factors for the DMs to consider and a balance between the external and internal factors in the SWOT analysis. The 24 opportunities, strengths, threats and weaknesses are presented in Table 5 along with their importance weights.

For individual ranking, the facilitators collected other relevant information on each factor, including the type of preference function and the threshold levels (q and p). The preference function type 4 for each factor was selected since it best suited for qualitative factors. For global ranking, the facilitators also gathered some relevant information on each DM. Since DMs had similar positions in the company, an equal weight of (20%) was assigned to each of them. For all practical purposes, the preference function type 5 was selected.

4.3. Step 3: Individual ranking and analysis

A decision matrix was designed using a Likert scale with 0 = unlikely to 5 = very likely to allow the DMs to evaluate the likelihood of each of the 24 SWOT factors for each of the five alternatives. Higher scores are preferred to lower scores for the positive factors, those identified as opportunities or strengths. In contrast, lower scores are preferred to higher scores for the negative factors, those perceived as threats or weaknesses. Consequently, the ideal and most attainable likelihood score on each positive factor, any opportunity or strength, is 5. Similarly, the ideal likelihood score on each negative factor, any threat or weakness, is 0. For each factor the relevant information, including the average scores, the type of preference function, the threshold value of q and p, and the weights were collected by taking into consideration the features of the alternatives. All opportunities and strengths factors are to be maximized, and threats and weaknesses factors are to be minimized. In this case, the preference function type 4 with $q = 0.5$ and $p = 1.5$ was utilized. These values are organized through a Delphi process where the facilitator instructs the DMs to state their preferences and values anonymously. Table 5 shows the weight of the factors for each DM. Table 6 presents the key factors and their performance scores.

Table 7 shows the results of the net flows and the complete ranking for each DM. Each DM was able to see his evaluation and

Table 6
The key factors and their performance scores.

Factor code	DM1					DM2					DM3					DM4					DM5				
	S	W	N	SE	E	S	W	N	SE	E	S	W	N	SE	E	S	W	N	SE	E	S	W	N	SE	E
POL07	2	2	3	1	2	2	2	3	1	1	2	1	2	1	1	2	2	3	1	2	2	2	3	1	1
LEG02	2	2	3	1	1	2	2	3	1	1	2	2	3	1	1	2	2	3	1	1	2	2	2	2	2
SOC04	3	2	3	1	2	4	2	3	1	2	3	2	3	2	1	4	2	3	1	2	3	2	3	2	1
GEO12	2	3	2	2	3	2	2	3	2	2	2	2	2	2	3	2	2	2	2	3	1	2	2	2	2
POL08	2	2	3	4	3	2	3	3	4	2	1	3	2	4	4	2	3	2	3	4	1	2	3	5	3
POL09	2	2	1	4	4	2	2	1	4	2	3	3	2	4	3	2	3	2	2	3	2	2	1	3	3
LEG03	2	3	2	2	2	2	2	3	2	2	3	2	3	2	3	2	3	2	3	2	2	2	2	2	2
LEG04	2	2	2	2	2	3	2	3	2	2	2	3	3	2	2	2	2	3	2	2	2	2	2	2	2
TEC09	2	3	1	5	4	2	3	2	5	4	2	2	2	3	3	3	2	2	4	4	2	2	1	3	4
CUL05	3	2	2	2	3	2	3	2	2	2	3	1	2	3	3	2	2	2	2	3	3	3	3	3	3
SOC05	3	3	2	2	3	3	3	3	2	2	2	3	3	3	2	2	4	4	3	3	3	2	2	2	2
GEO13	2	3	3	2	3	3	2	2	2	2	2	3	2	3	3	3	2	3	4	4	3	3	3	3	3
POL01	3	3	3	3	2	3	3	4	3	3	3	3	3	2	3	3	3	3	2	3	2	3	3	2	3
POL02	2	3	4	3	2	2	3	4	3	3	2	3	3	2	3	2	3	3	2	3	2	3	4	3	3
TEC01	3	2	3	2	1	3	2	4	2	2	3	3	3	1	2	2	2	3	2	1	3	2	3	1	1
TEC02	3	2	3	1	1	3	2	4	1	1	3	3	4	2	1	2	2	3	1	1	2	2	3	2	1
SOC01	3	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2	3	3	2	2	3	3	3	2	2
SOC02	3	2	2	2	2	3	2	2	2	2	3	2	2	3	3	3	2	2	3	3	3	2	2	3	3
SOC03	3	1	3	1	1	3	1	3	1	1	3	2	3	1	1	3	2	3	1	1	3	1	3	1	0
GEO003	3	2	2	2	1	4	1	2	2	1	4	2	1	1	1	3	2	2	1	1	5	2	2	1	1
ECN10	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	3	3	3	3	2	2	3	3	2	2
ECN12	3	3	3	2	2	3	3	3	2	2	3	3	3	1	2	3	3	3	2	2	2	3	3	2	2
POL04	1	2	2	3	2	2	3	3	3	3	2	3	2	4	2	1	2	2	2	3	2	2	3	4	2
LEG01	4	3	4	4	4	4	4	3	4	4	3	4	3	3	4	3	3	4	3	3	4	4	4	4	4

Table 7
The overall ranking of the five routes by each DM.

Pipeline routes	DM1		DM2		DM3		DM4		DM5	
	Net flow	Rank	Net flow	Rank	Net flow	Rank	Net flow	Rank	Net flow	Rank
Southern (S)	0.16	2	0.16	2	0.23	1	0.21	1	0.14	2
Western (W)	0.07	3	−0.10	3	−0.02	3	0.03	3	−0.09	3
Northern (N)	0.23	1	0.27	1	0.19	2	0.14	2	0.26	1
Southeastern (SE)	−0.22	4	−0.21	5	−0.27	5	−0.24	5	−0.21	5
Eastern (E)	−0.25	5	−0.11	4	−0.13	4	−0.14	4	−0.10	4

compare it with the ranking of the other DMs. Five DMs considered different opinions and judgments in ranking the proposed routes. DM1, DM2 and DM5 provided similar ranking for the Northern route (N) while DM3 and DM4 selected the Southern route (S) as the best alternatives. We had a noticeable difference of opinion between the two groups of DMs.

Next, we used the GAIA plane to highlight the conflicts, similarities and independencies among the factors and the DMs. The GAIA plane is

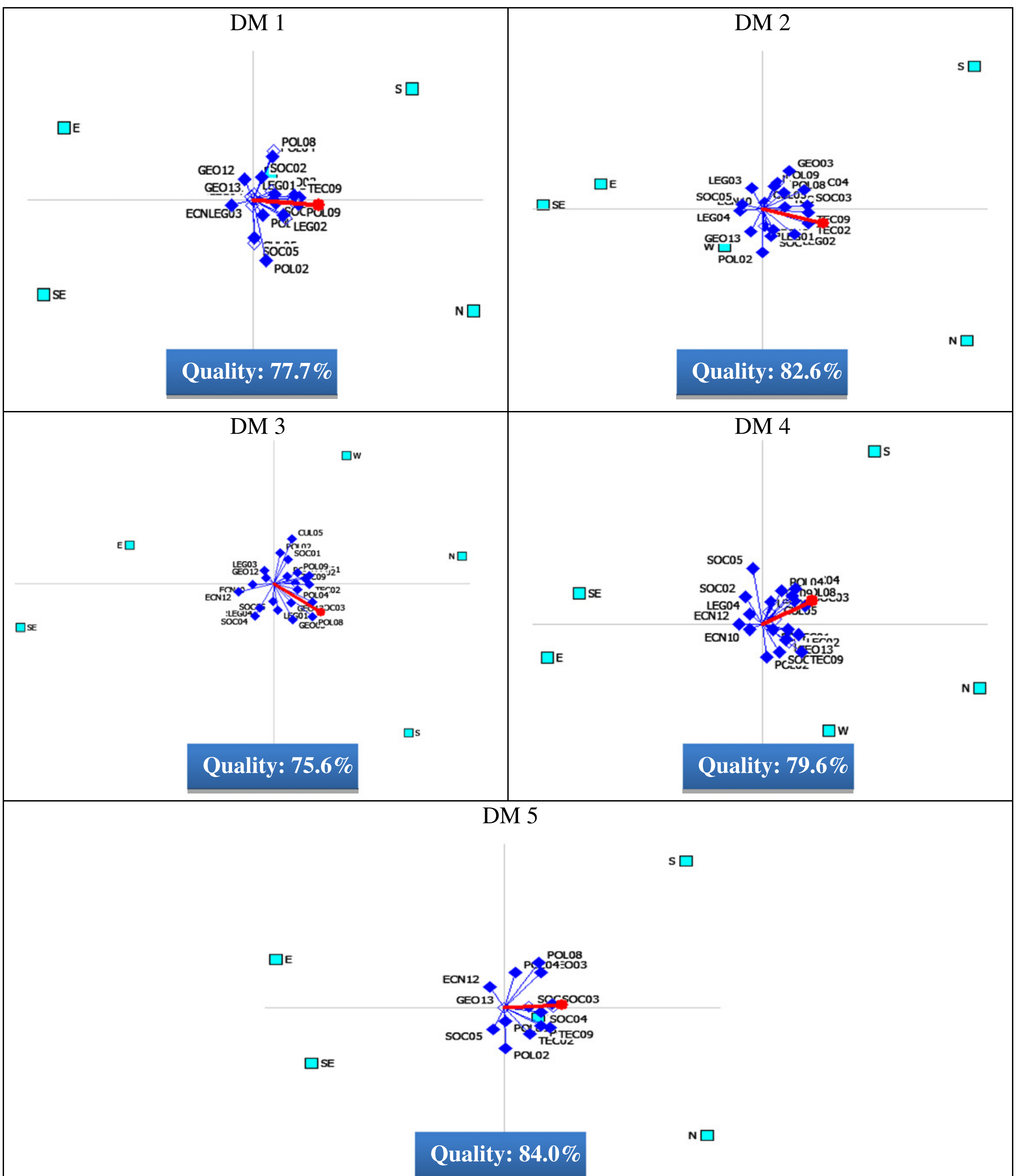


Fig. 5. The GAIA plane analysis for each DM.

Table 8
The decision matrix of the global evaluation.

	DM1	DM2	DM3	DM4	DM5
Weights	0.20	0.20	0.20	0.20	0.20
Max/Min	Max				
Preference function type	Linear				
p	0.25				
q	0.05				
Southern (S)	0.16	0.16	0.23	0.21	0.14
Western (W)	0.07	−0.10	−0.02	0.03	−0.09
Northern (N)	0.23	0.27	0.19	0.14	0.26
Southeastern (SE)	−0.22	−0.21	−0.27	−0.24	−0.21
Eastern (E)	−0.25	−0.11	−0.13	−0.14	−0.10

the result of a Principal Components Analysis (PCA) where a great deal of information is preserved after projection. As shown in Fig. 5, projecting the 29-dimensional space of factors onto a two-dimensional plane preserved 77.7%, 82.6%, 75.6%, 97.6% and 84% of the total information for DM1, DM2, DM3, DM4, and DM5, respectively. All five values in this study were greater than the 60% threshold value suggested by Brans and Mareschal (2005). This indicates the reliability of the information provided by the GAIA plane.

The length of the decision axis (red color vector) is a measure of its power in differentiating alternatives where the alternative routes are represented by green points and the factors are represented by blue vectors. In this setting, factor vectors expressing similar preferences on the data are oriented in the same direction, while conflicting factors are pointing in opposite directions. For example, for DM 1, the direction of the decision axis is towards Northern (N) and Southern (S) routes, which are the best alternatives in this decision problem. Other routes with opposite directions with respect to the decision axis appear the worst alternatives of Eastern (E) and Southeastern (SE) routes. Southern (S) route, for example, performs successfully on a number of factors such as POL08 and SOC02, and is never good or bad on the factors such as GEO12 and LEG02. This route also performs unsuccessfully on the factor such as LEG03 in the opposite side. Since some factors such asPOL02 and LEG03 are represented by orthogonal axes, they seem independent. The POL09 and SOC05 factors conflict with GEO12 and GEO13 since they appear in the opposite direction.

4.4. Step 4: Global ranking and analysis

The facilitators collected the net flow vectors of the five DMs and aggregated them into the group decision matrix presented in Table 8. A global PROMETHEE was then computed using Visual PROMETHEE (Mareschal, 2012). In this study, the Northern (N) and Southern (S) routes with the net flows of 0.72 and 0.65 were preferred from a group decision-making viewpoint, respectively. The net flows for Western (W) and Eastern (E) routes were −0.09 and −0.54. The Southeastern (SE) route with a net flow of −0.74 was considered to be the worst route. In summary, the overall ranking of the alternatives determined through according to the framework proposed in this study was: N > S > W > E > SE.

Next, we used the GAIA plane again but this time for the global ranking. Fig. 6 provides a visualization aid for understanding the different perceptions among the DMs as well as the performance of each alternative. The DMs are represented as vectors while the routes are represented as points. The high percentage (99.4%) means that the information preserved by the GAIA plane is reliable and rich. The direction of decision axis (π) is towards Northern (N) and Southern (S) routes, which are the best alternatives, and just the direct opposite of Southeastern (SE), which is the worst alternative route. The alternatives Western (W) and Eastern (E) do not perform well for all the DMs. Since the vectors of DM 3 and DM 4 are almost in the same direction, they possess quite similar preferences. This

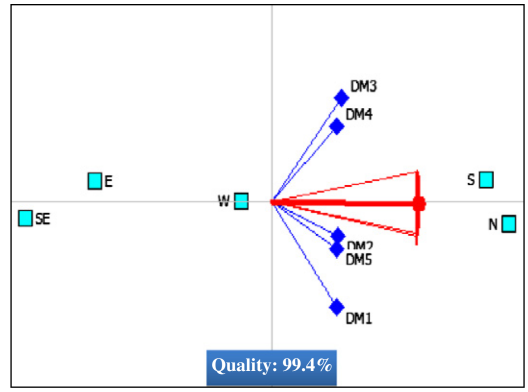


Fig. 6. The GAIA plane for the global evaluation.

is the case for DM 1, DM 2 and DM 5. DM 4 is independent of DM 2 and DM 5 in terms of the preferences as represented by the direction of the orthogonal axes. In summary, Fig. 6 shows that the Northern (N) route is the preferred choice for DM 1, DM 2 and DM 5 while the Southern (S) route is the preferred choice for DM 3 and DM 4.

5. Conclusions and future research directions

The increasing demand for energy in emerging economies severely challenged the world supply of oil and natural gas. In response, a number of foreign and local state-owned oil and gas companies are developing new pipeline routes to meet this increasing demand. The distances between the oil and gas reserves and the destination for energy processing can be thousands of miles over different countries and difficult terrain.

The Caspian Sea is the world's largest inland sea and has a significant amount of oil and natural gas reserves. In spite of the potential for the Caspian states to meet the increasing global demand for energy resources, only a few Caspian oil and natural gas export projects have become operational over the last decade. In this study, a GDSS was developed to evaluate five possible pipeline routes from the Caspian Sea region for a multinational oil and gas producer. The proposed system combined Delphi method and SWOT analysis with PROMETHEE and GAIA methods to capture the DMs' beliefs through a series of intuitive and analytical methods. Using the PROMETHEE-GDSS developed in this study, the DMs were able to decompose the process into manageable steps and integrate the results to arrive at a solution that was consistent with company's goals and objectives. It is hard to say for sure which route is the best, but, we made the selection process structured but yet flexible and comprehensive. The system encouraged DMs to think systematically and carefully consider environmental complexities and uncertainties.

The contributions of this paper are six fold: A GDSS was developed (1) to evaluate five possible pipeline routes from the Caspian Sea region; (2) to enhance the communication among the DMs throughout the Delphi process and SWOT analysis; (3) to perform all the necessary computing and graphics for PROMETHEE and GAIA; (4) to enrich the PROMETHEE solution with GAIA analysis; (5) to highlight the conflicts, similarities and independencies among the decision factors and the DMs; and (6) to enable the DM to better understand the available choices and the necessary compromises needed to achieve a better decision outcome.

The framework developed in this study can potentially lend itself to many practical applications. However, there are a number of challenges involved in the proposed research that provide a great deal of possibilities for future research. For example, incorporating simulation and optimization methods in the GDSS developed in this study will allow DMs to point out advanced economic analysis, technical design, or environmental impact estimation. Although the benefits of our GDSS are still emerging, the potential is enormous. We hope that our study can inspire others to pursue further research.

Appendix 1. The dominance concept

Let us assume alternative routes a' and a'' have likelihood scores $x' = (x'_1, \ldots, x'_p, \ldots, x'_m)$ and $x' = (x''_1, \ldots, x''_p, \ldots, x''_m)$ where $x_p(a') \equiv x'_p$ and $x_p(a'') \equiv x''_p$ for $p = 1, \ldots, m$. Furthermore, let us assume that preferences increase in each x_p. We say that x' dominates x'' whenever $x'_p \geq x''_p (\text{forall}\, p)$ and $x'_p > x''_p (\text{forsome}\, p)$. If x' dominates x'', then the alternative route a'' is not a candidate for "best alternative route," since a' is at least as good as a'' for every SWOT factor (given by $x'_p \geq x''_p$), and strictly better for at least one (given by $x'_p > x''_p$). Note that the idea of dominance exploits only the ordinal character of the likelihood scores (i.e., given two likelihood scores $x'_p = 3$ and $x''_p = 1$, we are interested in the relationship that $x'_p > x''_p$) and not the cardinal character of these likelihood scores (i.e., the fact that the difference between 5 and 3 is greater than the distance from 3 to 1 or that 3 is three times 1). Also note that dominance does not require comparisons between x'_p and x''_p for $p \neq q$.

References

Akdemir, I.O., 2011. Global energy circulation, Turkey's geographical location and petropolitics. Procedia Soc. Behav. Sci. 19, 71–80.

Anderson, C., Vince, J., 2002. Strategic Marketing Management. Houghton Mifflin, Boston.

Babali, T., 2009. Prospects of export routes for Kashaganoil. Energ. Policy 37 (4), 1298–1308.

Bai, Y., Zhou, D.Q., Zhou, P., Zhang, L.B., 2012. Optimal path for China's strategic petroleum reserve: a dynamic programming analysis. Energ. Econ. 34 (4), 1058–1063.

Balat, M., 2010. Security of energy supply in Turkey: challenges and solutions. Energy Convers. Manage. 51 (10), 1998–2011.

Bambawale, M.J., Sovacool, B.K., 2011a. China's energy security: the perspective of energy users. Appl. Energ. 88, 1949–1956.

Bambawale, M.J., Sovacool, B.K., 2011b. India's energy security: a sample of business, government, civil society, and university perspectives. Energ. Policy 39, 1254–1264.

Behzadian, M., Kazemzadeh, R.B., Albadvi, A., Aghdasi, M., 2010. PROMETHEE: a comprehensive literature review on applications and methodologies. Eur. J. Oper. Res. 200, 198–215.

Bilgin, M., 2007. New prospects in the political economy of inner—Caspian hydrocarbons and western energy corridor through Turkey. Energ. Policy 35, 6383–6394.

Bilgin, M., 2009. Geopolitics of European natural gas demand: supplies from Russia, Caspian and the Middle East. Energ. Policy 37, 4482–4492.

BP Statistical Review of World Energy, 2011. Retrieved March 1, 2012 from http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_report_2011.pdf.

Brans, J.P., 1982. Lingenierie de la decision.Elaboration dinstrumentsdaide a la decision.Methode PROMETHEE. In: Nadeau, R., Landry, M. (Eds.), Laide a la decision: Nature, instrument s et perspectives davenir. Presses de Universite Laval, Quebec, Canada, pp. 183–214.

Brans, J.P., Mareschal, B., 1994. The PROMCALC and GAIA decision support system for multicriteria decision aid. Decis. Support. Syst. 12, 297–310.

Brans, J.P., Mareschal, B., 2005. PROMETHEE methods. In: Figueira, J., Greco, S., Ehrgott, M. (Eds.), Multiple criteria decision analysis: state of the art surveys. Springer Science Business Media, Inc., pp. 163–196.

Brans, J.P., Vincke, P., 1985. A preference ranking organization method: the PROMETHEE method for MCDM. Manag. Sci. 31 (6), 641–656.

Briggs, Th., Kunsch, P.L., Mareschal, B., 1990. Nuclear waste management: an application of the multicriteria PROMETHEE methods. Eur. J. Oper. Res. 44, 1–10.

Chou, W.C., Lin, W.T., Lin, C.Y., 2007. Application of fuzzy theory and PROMETHEE technique to evaluate suitable ecotechnology method: a case study in Shihmen Reservoir Watershed, Taiwan. Ecol. Eng. 31, 269–280.

Colson, G., 2000. The OR's prize winner and the software ARGOS: how a multijudge and multicriteria ranking GDSS helps a jury to attribute a scientific award. Comput. Oper. Res. 27, 741–755.

Dalkey, N.C., Helmer, O., 1963. An experimental application of the Delphi Method to the use of experts. Manag. Sci. 9, 458–467.

Duarte, C., Ettkin, L.P., Helms, M.M., Anderson, M.S., 2006. The challenge of Venezuela: a SWOT analysis. Compet. Rev. 16 (3/4), 233–247.

Eden, C., 1990. Strategic thinking with computers. Long Range Plan. 223 (6), 35–43.

Effimoff, I., 2000. The oil and gas resource base of the Caspian region. J. Pet. Sci. Eng. 28 (4), 157–159.

Fischer, R., 1978. The Delphi Method: a description, review and criticism. J. Acad. Librariansh. 4 (2), 64–70.

Goletsis, Y., Psarras, J., Samouilidis, J.E., 2003. Project ranking in the Armenian energy sector using a multicriteria method for groups. Ann. Oper. Res. 120, 135–157.

Guliyev, F., Akhrarkhodjaeva, N., 2009. The Trans-Caspian energy route: cronyism, competition and cooperation in Kazakh oil export. Energ. Policy 37 (8), 3171–3182.

Hammond, J.S., Keeney, R.L., Raiffa, H., 1998. Even swaps: a rational method for making trade-offs. Harv. Bus. Rev. 76 (2), 137–148.

Haralambopoulos, D., Polatidis, H., 2003. Renewable energy projects: structuring a multicriteria group decision-making framework. Renew. Energ. 28, 961–973.

Hermans, C.M., Erickson, J.D., Noordewier, T., Sheldon, A., Kline, M., 2007. Collaborative environmental planning in river management: an application of multicriteria decision analysis in the White River Watershed in Vermont. J. Environ. Manage. 84, 534–546.

Hitt, M.A., Ireland, R.D., Hoskisson, R.E., 2000. Strategic Management: Competitiveness and Globalization, 4th ed. South-Western College Publishing, Cincinnati.

Hyde, K., Maier, H., Colby, C., 2003. Incorporating uncertainty in the PROMETHEE MCDA method. J. Multi Criteria Decis. Anal. 12, 245–259.

Iskin, I., Daim, T., Kayakutlu, G., Altuntas, M., 2012. Exploring renewable energy pricing with analytic network process—comparing a developed and a developing economy. Energ. Econ. 34 (4), 882–891.

Kaiser, M.J., Pulsipher, A.G., 2007. A review of the oil and gas sector in Kazakhstan. Energ. Policy 35 (2), 1300–1314.

Kakachia, K.K., 2011. Challenges to the South Caucasus regional security aftermath of Russian–Georgian conflict: hegemonic stability or new partnership? J. Eurasian Stud. 2, 15–20.

Keeney, S., Hasson, R.E., McKenna, H., 2006. Consulting the oracle: 10 lessons from using the Delphi Technique in nursing research. J. Adv. Nurs. 53 (2), 205–212.

Koh, W.T.H., 1994. Making decisions in groups a human fallibility approach. J. Econ. Behav. Organ. 23 (2), 195–214.

Leyva-López, J.C., Fernández-González, E., 2003. A new method for group decision support based on ELECTRE III methodology. Eur. J. Oper. Res. 148, 14–27.

Li, S., Kinman, R., Duan, R., Edwards, J., 2000. Computer-based support for marketing strategy development. Eur. J. Mark. 34 (5/6), 551–575.

Li, S., Davies, B., Edwards, J., Kinman, R., Duan, Y., 2002. Integrating group Delphi, fuzzy logic and expert systems for marketing strategy development: the hybridization and its effectiveness. Mark. Intell. Plan. 20 (4/5), 273–284.

Linstone, H., Turoff, M., 1975. The Delphi Method: Techniques and Application. Addison-Welsey, Reading.

Liu, B.-C., Tzeng, G.-H., Hsieh, C.-T., 1992. Energy planning and environmental quality management: a decision support system approach. Energ. Econ. 14 (4), 302–307.

Macharis, C., Brans, J.P., Mareschal, B., 1998. The GDSS PROMETHEE procedure—a PROMETHEE–GAIA based procedure for group decision support. J. Decis. Syst. 7, 283–307.

Macharis, C., Springael, J., De Brucker, K., Verbeke, A., 2004. PROMETHEE and AHP: the design of operational synergies in multicriteria analysis. Strengthening PROMETHEE with ideas of AHP. Eur. J. Oper. Res. 153, 307–317.

Madlener, R., Kowalski, K., Stagl, S., 2007. New ways for the integrated appraisal of national energy scenarios: the case of renewable energy use in Austria. Energ. Policy 35, 6060–6074.

Maier, P., 2010. How central banks take decisions: an analysis of monetary policy meetings. In: Siklos, P.L., Bohl, M.T., Wohar, M.E. (Eds.), Challenges in Central Banking. Cambridge University Press, Cambridge, pp. 320–352.

Mareschal, B., 2012. PROMETHEE-GAIA.netRetrieved from http://www.promethee-gaia.com/.

Martin, J.M., Fajardo, W., Blanco, A., Requena, I., 2003. Constructing linguistic versions for the multicriteria decision support systems preference ranking organization method for enrichment evaluation I and II. Int. J. Intell. Syst. 18, 711–731.

Mavrakis, D., Thomaidis, F., Ntroukas, I., 2006. An assessment of the natural gas supply potential of the south energy corridor from the Caspian region to the EU. Energ. Policy 34, 1671–1680.

Mintzberg, H., 1994a. Rethinking strategic planning—part 1: pitfalls and fallacies. Long Range Plan. 27 (3), 12–21.

Mintzberg, H., 1994b. Rethinking strategic planning—part 2: new roles for planners. Long Range Plan. 27 (3), 22–30.

Morais, D.C., De Almeida, A.T., 2007. Group decision-making for leakage management strategy of water network, resources. Conserv. Recycl. 52 (2), 441–459.

Ndour, B., Force, J.E., McLaughlin, W.J., 1992. Using the Delphi method for determining criteria in agroforestry research planning in developing countries. Agrofor. Syst. 19, 119–129.

Newnham, R., 2011. Oil, carrots, and sticks: Russia's energy resources as a foreign policy tool. J. Eurasian Stud. 2, 134–143.

Novicevic, E.P., Harvey, M.M., Autry, M., Bond III, C.W., 2004. Dual-perspective SWOT: a synthesis of marketing intelligence and planning. Mark. Intell. Plan. 22 (1), 84–94.

Okoli, C., Pawloski, S., 2004. The Delphi method as a research tool: an example, design considerations and applications. Inf. Manag. 42, 15–29.

Panagiotou, G., 2003. Bringing SWOT into focus. Bus. Strateg. Rev. 14 (2), 8–10.

Pasquarè, F.A., Tormey, D., Vezzoli, L., Okrostsvaridze, A., Tutberidze, B., 2011. Mitigating the consequences of extreme events on strategic facilities: evaluation of volcanic and seismic risk affecting the Caspian oil and gas pipelines in the Republic of Georgia. J. Environ. Manage. 92, 1774–1782.

Porter, M.E., 1987. Corporate strategy: the state of strategic thinking. Economist 23 (May), 21–22 (27-8).

Pudenz, S., Bruggemann, R., Voigt, K., Welzl, G., 2002. Multi-criteria evaluation and decision-support instruments for the long-term development of management strategies. Umweltwiss. Schadst. Forsch. 14 (1), 52–57.

Queiruga, D., Walther, G., Gonzalez-Benito, J., Spengler, T., 2008. Evaluation of sites for the location of WEEE recycling plants in Spain. Waste Manage. 28 (1), 181–190.

Raju, K.S., Duckstein, L., Arondel, C., 2000. Multicriterion analysis for sustainable water resources planning: a case study in Spain. Water Resour. Manage. 14, 435–456.

Schmidt, R.C., 1997. Managing Delphi surveys using nonparametric statistical techniques. Decis. Sci. 28 (3), 763–774.
Shaffer, B., 2010. Caspian energy phase II: beyond 2005. Energ. Policy 38, 7209–7215.
SÖderbergh, B., Jakobsson, K., Aleklett, K., 2010. European energy security: an analysis of future Russian natural gas production and exports. Energ. Policy 38, 7827–7843.
Sovacool, B.K., 2011. The interpretive flexibility of oil and gas pipelines: case studies from Southeast Asia and the Caspian Sea. Technol. Forecast. Soc. Chang. 78, 610–620.
Stegen, K.S., 2011. Deconstructing the "energy weapon": Russia's threat to Europe as case study. Energ. Policy 39, 6505–6513.
Tavares, M.E.E., Szklo, A.S., Machado, G.V., Schaeffer, R., Barboza Mariano, J., Sala, J.F., 2006. Oil refining expansion criteria for Brazil. Energ. Policy 34 (17), 3027–3040.
Tsygankova, M., 2012. An evaluation of alternative scenarios for the Gazprom monopoly of Russian gas exports. Energ. Econ. 34 (1), 153–161.
Umbach, F., 2010. Global energy security and the implications for the EU. Energ. Policy 38 (3), 1229–1240.
Valentin, E.K., 2001. SWOT analysis from a resource-based view. J. Mark. Theory Pract. 9 (2), 54–68.
Van Groenendaal, W.J.H., 2003. Group decision support for public policy planning. Inf. Manag. 40, 371–380.
Weihrich, H., 1982. The TOWS matrix-a tool for situational analysis. Long Range Plan. 15 (2), 54–66.