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A negotiation support system for resolving an international trans-boundary natural resource conflict

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A B S T R A C T

Post-Soviet legal governance regime of Caspian Sea – the largest inland body of water on earth – remains a source of conflict among the five coastal states of Azerbaijan, Iran, Kazakhstan, Russia, and Turkmenistan. Although different division methods have been suggested for sharing the sea and its valuable resources, the actual gain of the countries is unclear as the proposed methods focus either on the oil and gas or the areal share of the parties. The Caspian Sea Negotiation Support System (Caspian Sea NSS) is developed in this study to delineate optimal boundaries for sharing the sea through simultaneous consideration of the countries' areal and resource shares under different sharing methods. This NSS is a complex optimization model, with a solver engine that provides reliable results with a reasonable computational effort using a heuristic method. The model is run under different division scenarios to evaluate the sensitivity of each party's gain and locations of nautical boundaries to the division rules and the economic values of the resources. Results show a high sensitivity of the optimal nautical boundaries to the division rules and an indirect relationship between the allocated area and resource shares. The findings highlight the necessity for considering utility shares in negotiations as opposed to adopting areal division rules which ignore the utilities and might result in unfair resource allocation. The main policy implication of the study is that clarification of the countries' resource and areal gain under any suggested legal regime for governing the Caspian Sea is essential to the success of the negotiations.

1. Introduction

The multinational conflict over the legal status of the Caspian Sea, with its unique physiographic attributes and significant share of the world's energy and ecosystem resources, has remained unresolved since the breakup of the Soviet Union in 1991 (Mehdiyoun, 2000; Peimani, 2001; Zonn, 2001; Bahgat, 2002; Blum, 2003; Madani et al., in press). Lying between the Caucasus Mountains and Central Asia, the 376,000-km^2 sea is considered to be the largest inland body of water in the world. The proven and potential oil and gas deposits in the Caspian Sea are a significant proportion of global reserves (Blum, 2003). Additionally, the Caspian Sea is a valuable environmental resource that supplies local food and almost all of the world's black caviar (Zonn, 2001). Currently, redefining the Caspian Sea's legal status has become the subject of one of the world's insurmountable disputes, involving five littoral states of Azerbaijan, Iran, Kazakhstan, Russia, and Turkmenistan. The dispute is mainly over selecting a legal regime for allocation of the Caspian Sea's surface area as well as its precious oil and gas resources. Furthermore, the strategic importance of controlling the crossroad of energy and perhaps military power in the Central Asia adds a geopolitical dimension to the problem (Amirahmadi, 2000; Haghayeghi, 2003; Kaliyeva, 2004). After two decades of fruitless efforts, the negotiations to reach an agreement regarding the ownership of the sea should be expedited to prevent tragedy of the commons and to help alleviate environmental degradation and ecosystem deterioration due to overfishing and increased pollution from oil extractions (Zonn, 2001; Sheikhmohammady et al., 2010).

To this date, none of the various methods that have been proposed for allocating the Caspian Sea and its resources has gained full support from all of the involved parties, and a universal consensus over the sea's legal status is yet to be established (Kaliyeva, 2004; Sheikhmohammady and Madani, 2008b,c). Before the collapse of the Soviet Union, the Caspian Sea was governed based on two historical treaties between Iran and the Soviet Union.

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The 1921 Treaty of Friendship between Iran and Russia guaranteed free navigation for both parties and the 1935 Treaty of Establishment, Commerce and Navigation, which was reaffirmed in 1940, stipulated a coastal strip of 10 nautical miles from the shoreline as the territorial waters and exclusive fishing zones of the two states. (Mehdiyoun, 2000; Madani and Gholizadeh, 2011; Imen et al., 2012). However, after the fall of the Soviet Union, these treaties were no longer recognized by the new sovereign states which called for establishment of a new legal status for the sea to protect and promote their interests and prosperity (Mehdiyoun, 2000). One reason for failure of the dialogues for finding an acceptable legal regime to govern the sea is, perhaps, the ambiguity over the parties' obtainable benefits under each proposed division method. Although some proposed methods implicitly consider the gas and oil shares of each country, e.g., the 'Condominium' regime which allocates equal oil and gas shares to all countries (Sheikhmohammady et al., 2011, 2012), total gains of the parties are not very clear under other division methods such as median lines and equal shares of surface and seabed. The primary reason is that, typically, these division methods do not provide robust solutions to the problems associated with sharing the non-uniformly distributed energy resources. Furthermore, the division methods proposed in the scientific literature (O'Lear, 2004; Janusz, 2005; Askari and Taghavi, 2006; Sheikhmohammady and Madani, 2008a; Madani and Gholizadeh, 2011; Imen et al., 2012) focus mostly on determining the resource share of each country without suggesting appropriate nautical boundaries to secure the suggested resource shares.

Over the years, perhaps due to national, regional, and global geopolitical dynamics, Iran and, especially, Russia have changed their stances from supporting the 'Condominium' regime to the 'principle of sectoral division of the seabed' which is more favorable to the new sovereign states. As such, the nature of disputes over the legal regime of the Caspian Sea has shifted from whether the sea should be divided to how the division should be done (Mehdiyoun, 2000; Bahgat, 2002; Mojtahed-Zadeh and Hafeznia, 2003; Blum, 2003). Thus, to assist the negotiating parties, there is a need for developing an evaluation framework for simultaneous examination of different aspects of possible division methods, including the oil and gas shares, the areal shares, and the location of nautical boundaries.

Decision Support Systems (DSS) and Negotiation Support Systems (NSS) have been developed for transboundary water and environmental conflicts. Identifying and exploring the possible effects of alternative decision options and understanding the tradeoffs between their impacts through development of DSS and NSS can facilitate reaching an agreement among negotiators (Jelassi and Foroughi, 1989; Thiessen and Loucks, 1992; Kilgour et al., 1995; Thiessen et al., 1998; Nandalal and Simonovic, 2003; Janssen et al., 2006; Kersten and Lai, 2007; Kronaveter and Shamir, 2009a). Example cases include the acid rain negotiation between European countries (Hordijk, 1991), the Flathead River conflict between Canada and USA (Hipel et al., 1997), the conflict over Euphrates and Tigris rivers between Iraq, Syria, and Turkey (Kucukmehmetoglu and Guldmann, 2004), negotiations on the Canada-US Pacific salmon treaty (Noakes et al., 2005), the Jordan River conflict (Madani and Hipel, 2007), the Nile River conflict (Elimam et al., 2008; Madani et al., 2011), and international global warming negotiations (Heitzig et al., 2011), among others.

Optimization frameworks can facilitate the conflict resolution process (e.g., Kronaveter and Shamir, 2009a,b), using appropriate visuals to present the outcome of modeling for consensus building among multiple stakeholders (Kasprzyk et al., 2013). Analysis of trade-offs and stakeholders' gains under different proposed scenarios can be accomplished conveniently by formulating a representative optimization problem (e.g., Kucukmehmetoglu and Guldmann, 2010). Kasprzyk et al. (2013) developed an optimization framework for identifying and visualizing Pareto-approximate tradeoff sets for complex many-objective environmental problems, facilitating consensus building among a broad range of decision maker preferences. Arciniegas et al. (2013) demonstrated the importance of using graphical components to create appropriate visuals (e.g., map) in a spatial decision support system for effective communication of integrated knowledge obtained from multi-criteria spatial analyses. Barnaud et al. (2013) suggested that adding the spatial dimension is necessary for resource allocation negotiations (Barnaud et al., 2013).

This paper presents the Caspian Sea Negotiation Support System (Caspian Sea NSS), which is comprised of an optimization component along with an agent-based swap component working based on heuristic algorithm concepts. The proposed method facilitates obtaining optimal allocation of the sea, and determining the location of borderlines while addressing the allocation challenges posed by the presence of economically and strategically important energy resources. The novelty of the Caspian Sea NSS is in the use of a combination of optimization and map-based graphical components to facilitate the Caspian Sea negotiations by enabling the parties to estimate their gains under different division rules, and to find optimal nautical boundaries to secure their shares. While the focus of this study is on developing a tool for facilitation of the Caspian Sea negotiations, the proposed method is applicable to a class of common pool resource problems characterized by complex, multi-party negotiation over optimal allocation of area and valuable, heterogeneously distributed resources offered by the common.

In the next sections we explain the components of the Caspian Sea NSS along with different division scenarios. We then provide a discussion of the results, i.e., gains of negotiating parties in terms of areal and utility shares, and limitations of the proposed methodology, followed by conclusions.

2. The Caspian Sea Negotiation Support System

The developed allocation method consists of two modules, i.e., the Share Distribution Module (SDM) and the Swap Module (SM). Fig. 1 shows the flowchart of the proposed methodology.

The SDM provides an efficient initial optimization solution that will be used by the SM to find an improved optimal solution with respect to total transportation costs using a heuristic agent-based approach. First, the negotiating parties define their minimum required share of the sea summing up to 100%, which is provided to the SDM as an input. Furthermore, the SDM takes the digitized map of the sea as input and uses a solution merely based on minimum distance rule (as will be explained later) to match each country's allocated utility share to the corresponding pre-specified share of that country. This module is purely an allocation model whose outcome provides an efficient initially acceptable solution that can be further improved using the next module. Thus, the allocation algorithm does not necessarily incorporate some important elements of human decision making such as geographic optimality of the obtained solution, as well as feasibility of nautical borders. To address this shortcoming, the SM is developed to add an agent-based component to the NSS, increasing the flexibility of share allocation in the conflict resolution process.

The SM provides a platform for considering interactions among the littoral states in order to increase, among other things, the economic and strategic efficiency of the proposed solution by creating smooth marine borderlines at an optimal distance from their shores. This module incorporates insights from agent-based modeling by allowing to trace how the solution evolves in light

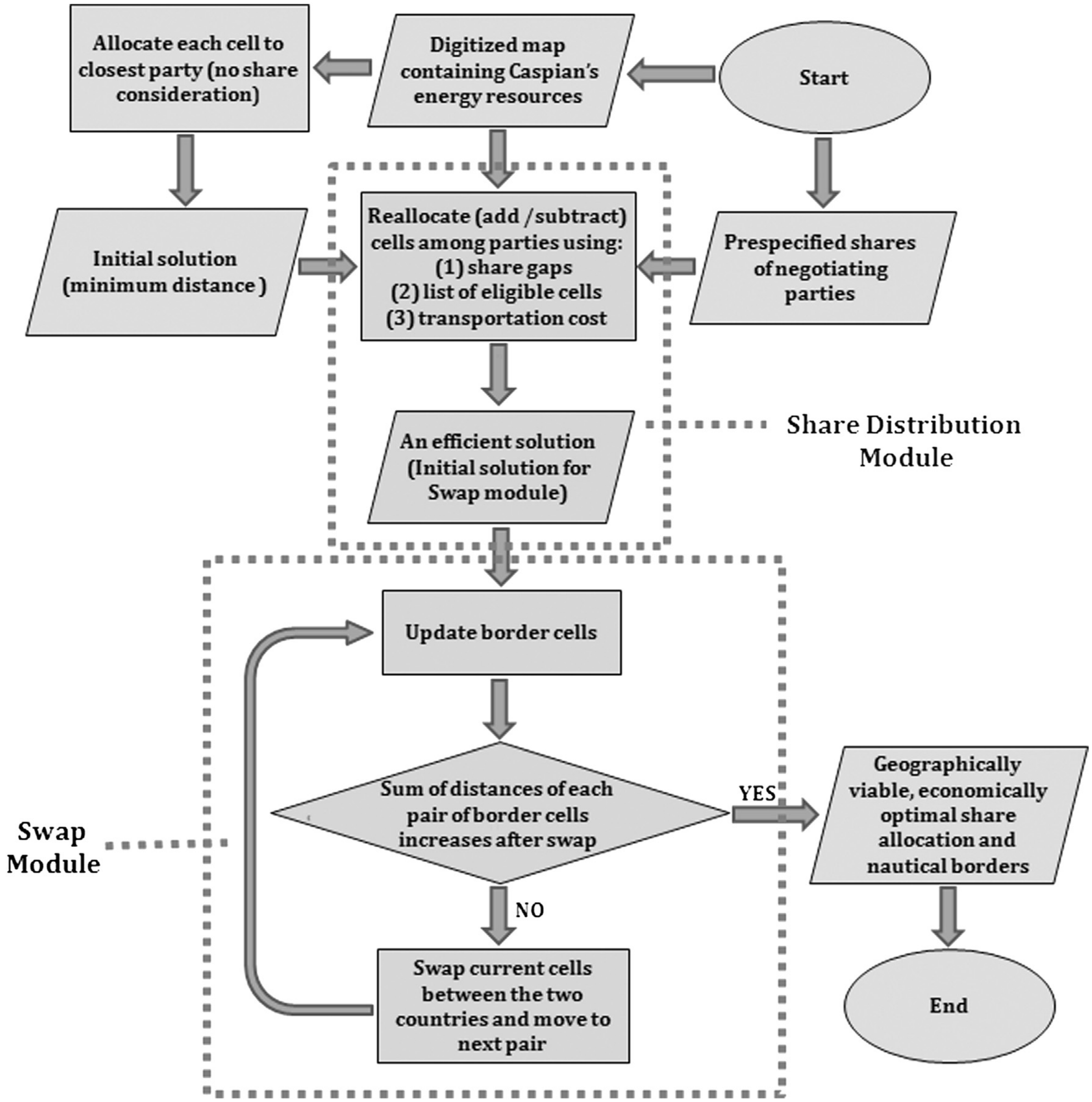

Fig. 1. Flowchart of the Caspian Sea NSS.

of changing interactions among players, driving their macro-scale behavior and attributes of the conflict (Drogoul and Ferber, 1994; Conte and Gilbert, 1995). In essence, agent-based modeling can facilitate characterization of the collective and individual behavior of conflict parties (Holland and Miller, 1991; Epstein and Axtell, 1996; Axelrod, 1997). The approach is particularly beneficial when decisions are made by a diverse group of decision-makers (or agents) whose interactions are characterized by complex behaviors and non-linearity, and when space is crucial and topology of interactions is heterogenous (Bonabeau, 2002). Several of these characteristics apply to the Caspian Sea's legal status conflict. When coupled together (Fig. 1), the SDM and SM can provide a geographically viable, economically justifiable allocation of the Caspian Sea. To facilitate the negotiations and interactions among the parties the NSS is used in an iterative process. Knowledge about the utilities together with visual outputs (maps) for different combinations of pre-specified shares can facilitate the negotiations. The iterative use of the NSS help the negotiating parties revise their expectations and make informed and improved decisions during negotiations.

In order to provide the basic input for the Caspian Sea NSS, a digitized map of the sea was produced, comprising about 24,000 cells, each representing 15.7 km^2 (3.9 km $\times$ 3.9 km) of the Caspian Sea area. Fig. 2 shows a map illustrating the orientation of the Caspian Sea shorelines alongside the boundaries of the sea and the littoral states. Furthermore, the map indicates the locations of proven gas and oil deposits. However, due to limited available information about the potential gas and oil reserves in the Caspian Sea, the digitized map does not distinguish between oil and gas fields, and the NSS treats the cells with proven energy resources in a combined manner. In other words, darker (green) cells in Fig. 2 may have one of the two energy sources or both of them.

The Caspian Sea NSS allocates each cell of the sea to individual countries, considering their main interests, the rules they set (e.g., pre-determined distance from their shore), and the value of the cell, which is determined based on the amount of energy and environmental resources that it holds. In this problem, each party is assumed to be interested in maximizing its gain (utility) from the sea. It is assumed that the utility of each country is a function of the total amount of oil, gas, and environmental benefits from the sea

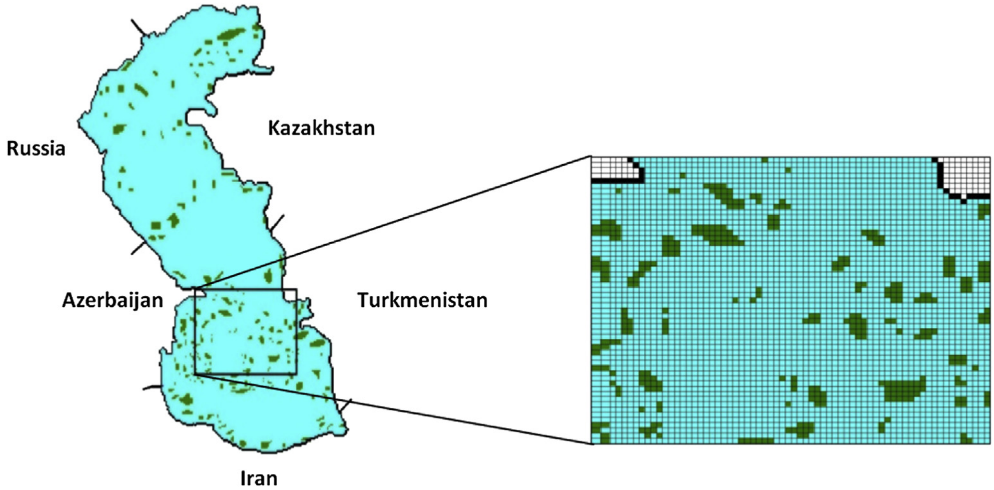

Fig. 2. Digitized map of the Caspian Sea showing the locations of proven oil and gas fields.

and the costs associated with exploitation of the allocated resources. Here, utility shares are determined exogenously, i.e., they are pre-defined fixed values and are given as constraints, and the sum of pre-determined shares equals the total value of Caspian Sea resources. Thus, each party needs to minimize its exploitation cost in order to maximize its utility. Exploitation cost can be defined as a function of extraction and transportation costs. Assuming the extraction cost to be essentially fixed, the surrogate for exploitation cost is the transportation cost, which varies by distance of the resource from the shore of the country that owns it. Although depth is an important factor in determining the extraction cost, it is not considered in this study due to lack of bathymetric data. Furthermore, it is assumed that ecosystem services are uniformly distributed. Thus, all cells are assumed to have equal environmental benefits, which are determined by dividing the total value of the environmental benefits of the Caspian Sea by the total number of cells. Besides environmental benefits, if the cell is located in gas or oil fields, it will have additional benefit from these energy resources. Assuming that all oil and gas cells are equally valuable, the oil and gas value of cells will be the total value of Caspian Sea oil and gas resources divided by the number of oil and gas cells (darker cells in Fig. 2). The Caspian Sea NSS makes decisions based on the following optimization model:

$$\text{Min} \sum_{c \in C} \sum_{(i,j) \in W} d_{ij,c} \times x_{ij,c} \tag{1}$$

subject to:

$$\sum_{c \in C} x_{ij,c} = 1 \quad \forall (i,j) \in W \tag{2}$$

$$\sum_{(i,j) \in W} v_{ij,c} \times x_{ij,c} \geq S_c \quad \forall c \in C \tag{3}$$

$$x_{ij,c} = 0/1 \quad \forall (i,j) \in W, \ \forall c \in C \tag{4}$$

where: $d_{ij,c}$ is the closest vertical/horizontal distance from the cell center (i, j) to the shoreline of the country c;$x_{ij,c}$ is a dummy integer variable that is 1 when the country c owns the cell (i, j) and 0 otherwise; W is the set of Caspian Sea cells; C is the set of the five negotiating parties involved; S_c is the pre-specified utility share of country c; and v_{ij} is the total value of gas, oil, and environmental resources of the cell (i, j).

The presented Caspian Sea allocation model (Equations (1)–(4)) solves a large-scale combinatorial optimization problem of integer programming type, with 24,000 × 5 binary variables. The first constraint of the optimization component (Equation (2)) ensures that each cell will be owned by one and only one country, and the second constraint (Equation (3)) requires that the total utility value of all the cells owned by country c should be greater than or equal to S_c. In this case, equality would be binding if the required shares of the five countries sum up to the total value of the sea. Providing an exact optimal solution to such a problem with reasonable computational efficiency is very challenging. The complexity of the problem further increases by the continuity requirement as the area allocated to each country should be continuous. Otherwise, the model may allocate disjoint cells to each country. Due to complexity of the problem, the Caspian Sea NSS employs a heuristic algorithm consisting of two modules.

2.1. Share Distribution Module

The first module, SDM, provides a proper initial solution for the next module (SM). This module processes the outcome of the preliminary solution from the minimum total distance (min-dist) rule, which allocates each cell to the nearest country. The SDM improves this preliminary solution by adjusting the utility shares iteratively such that the share for each country equals its pre-specified share. The algorithm for obtaining an efficient initial solution that satisfies the utility share expectation of the parties is as follows:

Step 0-Initial solution: Take the distance of each cell (i, j) to each country c ($d_{ij,c}$), π (stopping criteria), f (increase factor for distance), S_c (pre-specified share for country c), and (an) allocated map/cells (the initial min-dist solution) as inputs. Set $n = 1$ (number of iterations).

Step 1-Share calculation: For each country, determine its share and the deviation (shortage or excess) from the pre-specified shares (S_cs).

Step 2-Stopping criteria: If the sum of the absolute values of the deviations over all the countries is less than π, stop.

Step 3-Offsetting shares: Add shares from a country with higher (h) shares to a country with lower (l) shares (than their pre-specified shares) to reduce the difference between pre-specified and obtained utility shares.

In each step, the cells eligible for this process are chosen from a list sorted by the distance from the neighboring exchanging countries. In addition, the cells should satisfy the following rule:

$$d_{ij,l} - d_{ij,h} \leq \text{distance}(n) \quad (5)$$

where distance (n) increases in each iteration n, to increase the allowed distance gap, increasing the set of eligible cells that can be used for offsetting the differences in utility.
Repeat this for all the possible combinations of pair countries (one with higher share and the other with lower share than their pre-specified shares).

Step 4-Increasing the set of cells eligible for offset: $n = n + 1$, add to the distance (n) by the multiplier factor (f) and return to step 1.

The solution to this problem is a feasible set of $x_{ij,l}$'s which satisfy constraints 2 through 4. The defined distance parameter for the first iteration $(n = 1)$ is 2 km. This distance increases at each iteration using a constant increase factor for distance $(f = 2)$, adding only one more set of cells to be considered in the offsetting process (cells are 3.9 km in width). Furthermore, for the stopping criteria we assumed $\pi =$ the total value of all resources divided by 500, which prevents the shares from differing by more than 0.2% of the total value from the pre-specified shares.

The SDM iteratively exchanges the shares between the paired countries until the model converges to a solution which satisfies Equation (3). Eventually, the shares are set as close as possible to the pre-specified share values (S_c). The procedure of exchanging shares is driven by availability of a set of eligible cells to be exchanged between neighboring countries (Equation (5)), directing the search toward a solution with a good total distance value, although, perhaps, not the minimum. Therefore, the output of this module is a geographically delineated solution which matches the pre-specified shares and yields a proper objective function value.

2.2. Swap Module

The SM is needed to improve the efficiency of the solution algorithm and to ensure that solutions provided by the SDM are geographically viable. This module uses a solution algorithm, based on heuristic concepts, which benefits from some sort of intelligence in their search (Poorzahedy and Rouhani, 2007; Rouhani et al., 2013). Specifically, Tabu Search (Glover et al., 1995; Onwubolu, 2002), which provides a practical solution method for non-linear combinatorial optimization problems, is used by the SM. The search method is based on memory structures and utilizes an iterative neighborhood search procedure that also attempts to avoid local optima. Tabu search algorithms have been used in a number of water resources and water and environmental engineering problems as well as natural resource management applications such as water network optimization (Cunha and Ribeiro, 2004), groundwater remediation (Zheng and Wang, 1999), and timber harvest scheduling (Bettinger et al., 1997), among others.

The fundamental premise for the SM is that although the SDM provides a proper initial solution, in practice, negotiating agents will make decisions more rationally by taking logistical considerations into account and try to minimize the resource extraction costs further. Thus, the SM takes the output of the SDM and improves the solution based on the iterative move-swap process derived from the Tabu Search concepts. The algorithm can be stated as follows:

Step 0-Initial solution: Take the assigned map (cells) from the SDM as an input. Set $n = 1$.
Step 1-Determining border cells: Determine the border cells for each country (cells with at least one adjacent cell owned by another country). Name this set $B(c)$, where c is the country owning the border cells.
Step 2-Swapping: For each combination of two neighboring countries $(c1, c2)$, if cell $(i1, j1)$ is owned by the country $c1$ and cell $(i2, j2)$ is owned by the country $c2$ $(x_{i1,j1,c1} = 1$ and $x_{i2,j2,c2} = 1)$, and both are adjacent border cells $(x_{i1j1,c1} \in B(c1)$ and $x_{i2j2,c2} \in B(c2))$, and if:

$$d_{i1j1,c1} + d_{i2j2,c2} \geq d_{i1j1,c2} + d_{i2j2,c1} \quad (6)$$

then, swap these two cells: $x_{i1j1,c2} = 1$ and $x_{i2j2,c1} = 1$ and $x_{i1j1,c1} = 0$ and $x_{i2j2,c2} = 0$

Step 3-Stopping criteria: Stop if there is no cell left for swapping.
Step 4-Iteration loop: $n = n + 1$. Go to Step 1.

In effect, Equation (6) guarantees that, in each iteration, the swapping process improves the objective function. The swapping process is done by changing the dummy variable $x_{ij,c}$ from 0 to 1 or vice versa. The procedure ends when there are no more cells available for swapping. Although this technique may not result in finding the global optimum solution, it allows for finding an effective solution to the Caspian Sea allocation optimization problem with a reasonable computational effort while ensuring the geographic viability of each country's share through delineating smooth, continuous borderlines.

3. Division scenarios

To underline the utility of the developed model in facilitating the Caspian Sea negotiations some division methods that have been suggested to resolve the problem were simulated in this study. Typically, the suggested methods focus mostly on the areal shares, or they offer an implicit means of accounting for the available energy resources by equally dividing them among the littoral countries – a method which is the least favorable to the new sovereign states (Mehdiyoun, 2000; Sheikhmohammady and Madani, 2008a). While the areal share division methods bear promises for facilitating an agreement, they do not provide a framework for reaching a lasting compromise. Because of the presence of substantial amount of energy deposits under the seabed, the region is prone to future severe conflicts over energy resources. Therefore, for a division methodology to yield a sustainable agreement, it should encompass an explicit means for allocating energy resources as well. To address this issue and to provide insights into the significance of incorporating energy-related economic values, a utility-based allocation approach was used in this study to delineate nautical borders. Providing a quantitative measure of the negotiating parties' gains under each division method, which has not been done so far, can facilitate the negotiation process. In fact, absence of this information is deemed to be part of the reason for the failure of the negotiations. In this study, we have looked at division scenarios with logical and practical basis. Additionally, we tested different resource values to partly account for the uncertainty associated with lack of information and to better understand the sensitivity of optimal division of the sea to the value of resources it holds.

The Caspian Sea NSS was run under a set of different division scenarios as shown in Table 1. The division scenarios were formulated based on the division rules (i.e., minimum distance, equal area, equal share, and border share), and by considering the cell values and the minimum required shares of the parties. The first two division scenarios, i.e., scenarios 0 and 1 do not consider the value of resources. Scenario 0 tries to minimize the total distance, assuming that the resource should be allocated to the country with the lowest exploitation cost. In other words, this scenario dictates sharing the sea by allocating the cells to the closest country, without considering the cell's value in terms of energy deposits. In order to run the NSS under this scenario, Equation (3) is removed from the optimization component as this equation accounts for differences in resources values in the study area.

Scenario 1 dictates the equal area rule, based on which the areal shares of the five countries from the Caspian Sea will be equal (each country receives 20% of the sea area). To solve this problem, cell values are set equal to the total resources value of the sea divided by the total number of cells. Scenarios 2–10, each with different resource values, enforce equal utility shares from the sea (scenarios 2–8), or allocate shares relative to the length of the shorelines (scenarios 9–10). The base value of Caspian Sea energy resources was considered to be 10,000 billion dollars, based on Sheikhmohammady et al. (2011). To our knowledge, no study provides a solid estimation of total value of ecosystem services of the Caspian Sea. In this study, the base value of ecosystem (other) resources of the sea was assumed to be 10 billion dollars based on Gholizadeh (2010) and Imen et al. (2012), as well as discussions with the staff of the Caspian Environment Programme and according to the United Nations Development Programme's CaspEco Project (UNDP, 2009). Furthermore, due to the uncertainty associated with these figures, the model was run using different resource values (e.g., 5000 and 20,000 billion dollar for energy resources, and 100 and 1000 billion dollar for other resources) to assess the sensitivity of final results to resource values.

4. Results and discussion

Fig. 3 shows the value of the objective function (transportation distance) of the solution found under different division scenarios. The results show that the optimum value of the objective function (sum of distances of the cells from the shorelines of the country they are allocated to), representing the transportation costs, does not vary significantly by changing the allocation rules, even when allocation is done based on shoreline lengths. As shown in the figure, the minimum distance division rule (scenario 0) produces the minimal transportation distance (objective function value). When the base energy resource value of $10,000 billion is used in different scenarios (Scenarios 0, 1, 4, 5, 6, 9 and 10) the equal share division rule provides the second shortest transportation distance. The equal area division scenario (Scenario 1), approximately, gives an average value for the objective function. The border share scenario results in the highest total transportation distance (highest transportation cost).

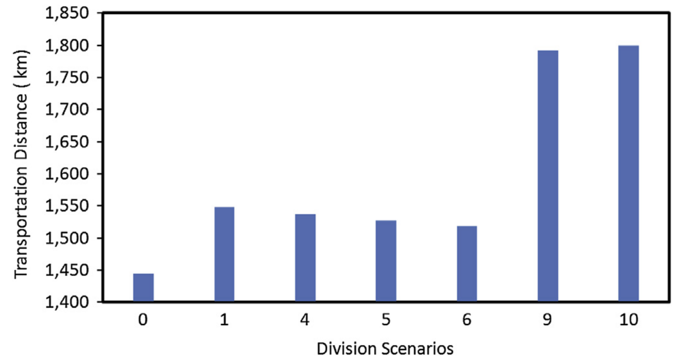

Fig. 3. Value of objective function (transportation distance) under different division scenarios.

Tables 2 and 3 summarize the utility and areal shares of the five countries, found by the Caspian Sea NSS for different division rules (Table 1). In addition, Figs. 4 through 6 illustrate the areal share of each country under different division scenarios. Comparison of these tables clearly indicates the mismatch between the areal shares and the gains (utilities) of the parties from the area allocated to them. This finding highlights the necessity for considering utility shares in negotiations. Simultaneous consideration of the areal and utility shares requires novel tools such as the Caspian Sea NSS, which can facilitate the negotiations by providing visual and economic information to the parties. Here, we discuss the tabulated results in conjunction with the shape of aerial shares to demonstrate the importance of this insight.

Caspian Sea NSS develops a color-coded map of the sea to visualize the countries' areal share trade-offs under various division rules. Fig. 4a and b display the resulting Caspian Sea division using the minimum distance (scenario 0) and equal area (scenario 1) division rules, respectively. Under scenario 0 the model will allocate the highest to lowest utility shares, which range approximately from 24% to 16% (Table 2), to Turkmenistan, Azerbaijan, Kazakhstan, Iran, and Russia (Fig. 4a). However, as presented in Table 3, under the same division scenario Kazakhstan gains the largest areal share (more than 30%) while the smallest areal share (15%) goes to Iran. The areal shares of the remaining three countries will be between 18% and 19%. The utility shares of the countries are distributed more evenly as compared with corresponding aerial shares, and the

Table 1
The Caspian Sea division scenarios.

Division rule	Scenario no.	Total value of energy resources (billion $)	Total value of other resources (billion $)
Minimum distance	0	10,000	10
Equal area	1	10,000	10
Equal share	2	5000	10
	3	5000	100
	4	10,000	10
	5	10,000	100
	6	10,000	1000
	7	20,000	10
	8	20,000	100
Border share	9	10,000	10
	10	10,000	100

Table 2
Summary of utility shares of the 5 countries (in % of total).

Scenario	Azerbaijan	Iran	Kazakhstan	Russia	Turkmenistan
0	21.74	17.53	21.10	15.62	23.91
1	24.04	23.35	19.76	11.72	21.13
2	19.94	20.01	20.02	20.03	20.00
3	20.02	20.03	20.01	19.97	19.98
4	20.01	20.01	20.02	19.96	20.01
5	20.02	19.99	20.03	19.95	20.00
6	19.99	19.98	19.99	20.01	20.03
7	20.01	20.01	20.01	19.95	20.01
8	19.99	20.00	20.04	20.00	19.98
9	15.05	15.98	36.01	16.92	16.04
10	14.95	16.03	36.02	17.01	15.99

Table 3
Summary of areal shares of the 5 countries (in % of total).

Scenario	Azerbaijan	Iran	Kazakhstan	Russia	Turkmenistan
0	18.7	15.0	30.3	18.0	18.0
1	20.0	20.0	20.0	20.0	20.0
2	14.6	17.5	25.7	29.8	12.4
3	14.2	17.7	29.0	27.2	12.0
4	15.1	17.4	27.3	27.4	12.8
5	14.9	17.6	28.3	26.4	12.8
6	16.7	17.8	26.6	26.2	12.7
7	17.8	17.4	24.4	27.8	12.6
8	15.8	17.6	24.6	29.1	12.9
9	11.2	15.3	44.9	19.2	9.4
10	11.0	14.7	44.0	20.5	9.8

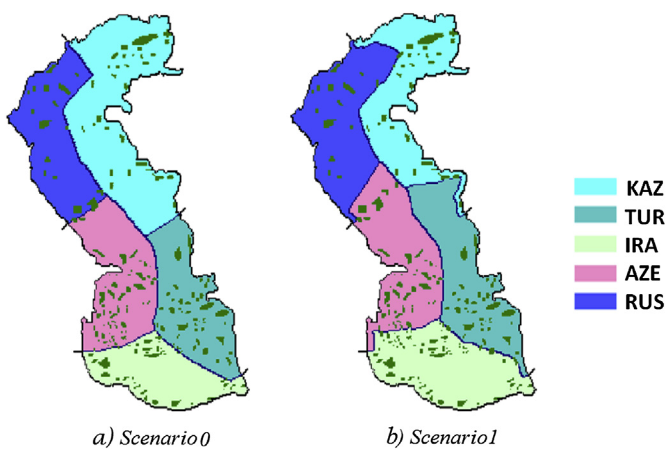

Fig. 4. Dividing the Caspian Sea based on the minimum distance and equal area division rules (scenarios 0 and 1).

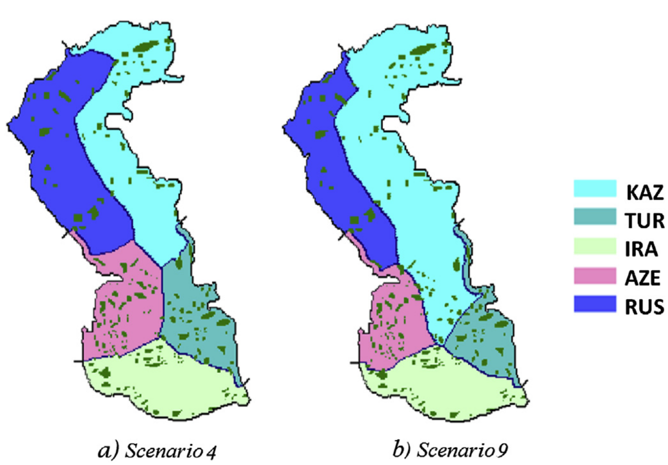

Fig. 5. Caspian Sea maps based on equal share (scenario 4) and border share (scenario 9).

resulting map is insensitive to the value of Caspian Sea resources. Furthermore, scenario 1 will allocate the largest utility share to Azerbaijan whereas Russia's share will be about 12%. Iran will have the second largest utility share while Turkmenistan ranks third and Kazakhstan fourth (Table 2). Similar to scenario 0, under scenario 1 the resulting map is insensitive to the total resources value. As shown in Fig. 4b, this scenario may provide nautical borders that are geographically unviable (e.g., for Kazakhstan). It is worth noting that the shapes of aerial shares are heavily affected by the required 10 mile distance from shoreline.

Fig. 5a and b, respectively, show the resulting maps for equal share division rule (scenario 4) and the corresponding border share scenario in terms of the total value of other resources (scenario 9). Under scenario 4, delineation of nautical borders is carried out such that the utility share of each country will be about 20%. This scenario allocates the largest areal share (over 27%) to Russia and Kazakhstan. Iran's areal share will be over 17%, and Azerbaijan (15%) and Turkmenistan (about 13%) will have the smallest areal shares (Table 3). Border share division rule (scenario 9) will allocate the largest utility share (36%) to Kazakhstan followed by Russia, Turkmenistan, Iran, and Azerbaijan whose utility shares are within the range of 15–16% (Table 2). Kazakhstan will also gain the largest areal share of all scenarios (about 45%) since this country has the longest coastline (Table 3). Russia (19%) and Iran (15%) will gain the second and third largest areal shares while the smallest shares go to Azerbaijan (11%) and Turkmenistan (9%). It is interesting to note that, although scenario 9 will allocate the smallest areal share to Turkmenistan, this country's gains in terms of utility share is larger than that of Iran and Azerbaijan due to presence of abundant energy resources within Turkmenistan's nautical borders.

Fig. 6 shows the resulting maps for different non-energy resource values only under the equal utility shares division rule (scenarios 4–6). It is observed that rerunning the model using different non-energy resource values will not affect the areal gain of the countries significantly. This is because oil and gas cells are much more valuable than other cells, and changing the value of other resources does not change the allocated shapes by much. As such, even when the total value of other resources is increased from \$10 billion (Fig. 6a) to \$100 billion (Fig. 6b), and then to \$1000 billion (Fig. 6c), the areal share order of the countries varies only slightly due to decrease in the share of the countries with largest areal share (Russia and Kazakhstan) and increase in the share countries whose areal shares are the smallest (Iran, Azerbaijan, and Turkmenistan).

The resulting maps illustrate that the final areal results are highly sensitive to the division rule. Interestingly, even when the values of the sea resources are changed, the areal maps do not vary significantly as long as the division rule remains the same, supporting the fact that the results are more sensitive to the division rule than to changes in the resource values. However, the latter conclusion may not remain valid if the environmental benefits increase to the level that they become significant as compared to the value of energy resources to which the Caspian Sea's areal division maps are currently most sensitive. Furthermore, for scenario 9 (border share), the allocation will have a peculiar, crooked shape which makes it difficult to apply in practice. Scenario 1 also forms strange shapes owing to problems arising from allocation of equal areas when having different border line sizes. Another interesting observation from a practical standpoint is that for all scenarios there are some allocated cells (areas) that are much closer to another country in terms of distance, which may bring about legal problems with respect to ownership of these areas.

As discussed and is observable from Fig. 4 through 6 and Tables 2 and 3, because of the non-uniform distribution of gas and oil resources, the utility share of each country is not directly related to its areal share. The important policy implication of this finding is that division rules which solely focus on areal shares are unlikely to lead to fair division of the sea. Therefore, it is essential for the negotiating parties to quantify their gains in terms of utility shares from the resource, rather than basing the negotiations solely on physically tangible units such as areal share, volumetric share, and the like. Put differently, the idea of utility share may help clarify the stakeholders' gains under different division rules, which may lead to increased cooperation. As a result, placing the emphasis on the utility shares can transform a zero-sum problem to a win–win resolution (Madani, 2011; Madani and Lund, 2012).

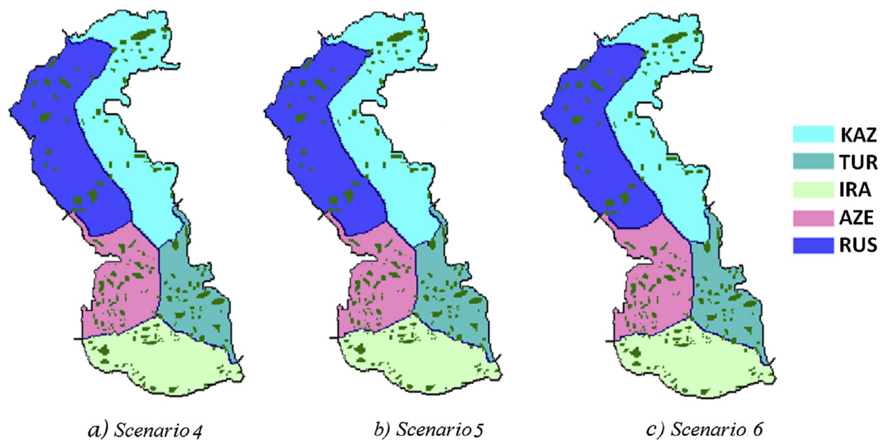

Fig. 6. Caspian Sea maps based on the equal utility share division for different resources values.

5. Limitations

While simplifications are inherent to modeling efforts in general, the consequent limitations must not be neglected when interpreting the results and discussing the value of the developed model (Madani, 2013). The Caspian Sea NSS is indeed a promising "proof of concept." A significant advantage of the proposed methodology over previous methods is that, using an integrated approach for quantifying the agents' gains, it delineates nautical boundaries to secure the negotiating parties' shares, which is critical in practical applications. The results show that the NSS can facilitate negotiations as an illuminating tool, providing more information to the stakeholders, who are unsure about their gain out of the possible resolutions to the conflict. However, the "Beta" version of the Caspian Sea NSS has some limitations whose proper understanding will provide direction for future research to improve the NSS or to develop other useful conflict resolution frameworks. The extant limitations of the Caspian Sea NSS are discussed as follows:

- Fixed resource values: While oil and gas prices are highly variable in the global market as the world prepares to transition to alternative energy sources (Mirchi et al., 2012), the NSS considers fixed prices for the oil and gas resources. This ignores the price variability, which can affect the extraction and operation policies of the riparian states. Similarly, the NSS considers fixed values for the ecosystem services. Nevertheless, their values and especially the value of sturgeon can vary based on the ecosystem conditions, location, and fishing policies of the riparian states.
- Lumped oil and gas fields: Currently, the NSS cannot distinguish between the oil and gas cells, which creates inaccuracies in estimation of the values of oil and gas cells.
- Partitioned oil and gas fields: Based on the existing formulation, optimal boundaries might transect oil/gas fields. In that case, one oil/gas field might need to be shared by multiple countries. This may result in some additional conflicts and competitions over sharing the resource. For example, Iran and Qatar are currently experiencing some difficulties over sharing the gas and oil fields in the Persian Gulf. In the future, the model formulation might be revised such that each gas/oil field will have a unique owner.
- Uniform distribution of ecosystem services: The NSS assumes that the ecosystem services have been distributed uniformly. Therefore, all cells have equal environmental values. However, the marine species with different values are not available in all parts of the sea. For example, some areas with higher water depth may have more sturgeon. Furthermore, the marine species are mobile and their habitat area might not be fixed.
- Depth-dependence of extraction costs: While oil and gas extraction costs depend on both water depth and distance from the coast (transportation cost), the NSS neglects the water depth portion of the extraction costs. However, water depth is highly variable across the Caspian Sea. Therefore, the extraction costs can be dramatically higher in deep areas (e.g., close to Iranian border), affecting the total utilities of the countries owning deeper waters.
- Heuristic solution: Due to the complexity of the optimization model, a heuristic method is used to solve the problem. Therefore, the solution is not exact and the NSS might fail to find the global optimum solution. Nonetheless, when applied to the Caspian Sea problem, the solution algorithm proved capable of allocating utilities very close to the minimum required shares of the negotiating parties (Table 3). The maximum error of 0.5% is observed under scenario 9 where the suggested utility share of Russia is 16.92% instead of 17%.
- Excludability and rivalrousness: Here, it is assumed that the negotiators are interested in privatizing the Caspian Sea and its resources, converting it from a common pool resource to a private resource. Privatization is done through allocation of rights to particular areas of the sea. While the nature of negotiations and the parties' zero-sum perceptions of the allocation problem justify this assumption, more efficient management of the Caspian Sea system (e.g., under the Condominium regime which is currently considered as an option by the negotiators) might not necessarily treat the system and its valuable components as excludable and rival.

In spite of the noted limitations, the Caspian Sea NSS can play a critical role in supporting and giving a direction to the negotiations. Most of the limitations are due to unavailability of data which can be addressed as more data becomes available in the future, and more insights are generated by further research. For example, an improved version of the NSS could incorporate information on water depth and habitat locations of valuable fish species. Even if the stakeholders express concerns about the reliability of the data used in the Caspian Sea NSS, it can nonetheless be used for facilitating the negotiations by enabling the parties to run the model based on their own values and reasonable expectations (e.g., different division methods, different resource values, and utility shares). This would help the negotiators better understand the sensitivity of the utilities to different factors that need to be considered during negotiations.

6. Conclusions

Although many division methods have been proposed for sharing the Caspian Sea, for the last two decades, the negotiating countries have not been able to reach a compromise over the legal status of the sea. One reason for such a failure is lack of clear vision about the gains of each country and/or the position of the marine borders under different division methods as the proposed methods mainly focus on the areal shares of the countries or their utility shares. The motivation of this research was to develop a tool which promotes the fair allocation of the sea and its resources by allowing for simultaneous evaluation of utility and areal shares of the countries under different possible division methods. Despite some limitations that can be addressed in future research, the developed NSS was found to be a promising tool in providing valuable insights into the problem. The Caspian Sea NSS can facilitate negotiations by providing better information on what the parties would gain under different solutions to the problem. By using the NSS, the parties will learn about the sensitivity of their gains to different factors that they must consider in negotiations. Furthermore, a significant advantage of the proposed methodology over previous methods is that, using an integrated approach for quantifying the agents' gains, it delineates nautical boundaries to secure the negotiating parties' shares, which is critical in practical applications. While the developed tool does not suggest new division solutions, it can be used to effectively evaluate the fairness and efficiency of different division rules ("what if" scenarios). Nevertheless, the integrative NSS application process can help the negotiators develop new division solutions.

The Caspian Sea NSS is a complex optimization model, with a solver engine that provides reliable results with a reasonable computational effort (20 min for each run on average) using a heuristic algorithm. The results demonstrated a high sensitivity of the resulting areal map of the sea to the division rule and a minor sensitivity to the environmental resource values as long as the value of the energy resources is significantly higher than that of environmental resources. The results indicate that the parties must consider utility shares in their negotiations instead of adopting areal division rules. The idea of switching from negotiations over observable (tangible) units (e.g., area, volume, etc) to utilities can facilitate the negotiations, increasing the chance of obtaining fair and efficient results.

Due to non-uniform distribution of energy resources in the sea, the utility shares of the parties do not have a direct correlation with their areal shares, suggesting that division methods which only consider the areal shares may not lead to fair division of the Caspian Sea. The Caspian Sea NSS helps determine the location of nautical boundaries while addressing challenges posed by the presence of economically and strategically important energy resources. The approach is applicable to a class of common pool resource problems involving multi-party negotiation over allocation of area and valuable non-uniformly distributed resources offered by the common and other similar optimization problems.

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