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# Role of culture in water resources management via sustainable social automated negotiation

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ABSTRACT

Increased competitions for water resources in many regions worldwide call for cooperative approaches. The competitions are complex for humans to resolve due to numerous alternatives and different or conflicting preferences of multiple stakeholders over multiple criteria, which might even oppose desirable environmental objectives. Parties also have incomplete information about the preferences of the counterparties. Electronic negotiation, empowered by intelligent agent technology, is a combination of artificial intelligence, economics, and psychology to find beneficial joint agreements in complex paradigms such as this. This study investigates a multilateral sustainable automated negotiation among intelligent agents representing stakeholders, including the legal party 'nature' as one of the stakeholders. It defines decision criteria and alternatives in the framework of cultural factors, elicits preferences of the stakeholders regarding the criteria without their intervention using a multi-criteria decision-making method, prunes the solution space before starting the negotiation by recognizing a general social treaty, determines the multi-issue specific treaty by learning the stakeholders, and demonstrates bidding and acceptance strategies.

## 1. Introduction

"Whiskey is for Drinking; Water is for Fighting Over" (attributed to Mark Twain) and "The wars of the future will be fought over water not oil" [1,2] well address "Anyone who solves the problem of water deserves not one Nobel Prize, but two — one for science and the other for peace" (by John F. Kennedy). Conflicts over water resources have presented challenges worldwide from 3000 BC until now [3]. Despite enough total water on earth, only one percent is suitable for human use. Human life depends on water for drinking, agriculture, industry, navigation, hydroelectric power, and leisure. Since nature has not distributed this resource equitably, climate change and the malfunctions of governments have made it worse, and it has become a geopolitical bargaining chip. Droughts, floods, heatwaves, and wildfires are global disasters that affect both arid and green regions. Scarcity in water and too much water can cause problems, and one nation or political entity should not deprive or flood another. Conflicts over shared rivers, lakes, and groundwaters due to water use, water quality, and water distribution are predicted to increase [3–6].

Kofi Annan believes that "the water problems of our world need not be only a cause of tension; they can also be a catalyst for cooperation ...If we work together, a secure and sustainable water future can be ours". [7], and the cooperation will save us and our environment. Conflicts and cooperations are two sides of the interaction [8,9] in developing sustainable water resources management (Fig. 1). Sustainability balances the right to development, responsibility to future generations, respect for nature, and intergenerational equity [10]. However, local, private, and immediate solutions might cause global environmental damages in the future. Therefore, in addition to different and maybe opposing preferences of the parties, concern for the environment also makes resolving these problems more difficult. Preservation of environmental resources is common to all parties and requires collective actions [11–13], the public involvement.

### 1.1. The problem statement

Iran shares more than ten transboundary water resources with its neighbors, including Turkey, Armenia, Azerbaijan, Turkmenistan, Iraq, Afghanistan, and the Arab States of the Persian Gulf [14,15]. Among the neighbors, the Afghanistan-Iran water conflict started in the 1870s when their border was created along the main branch of the Helmand River. The water treaty, signed first in 1939, was never implemented due to multiple political changes and revolutions in both countries

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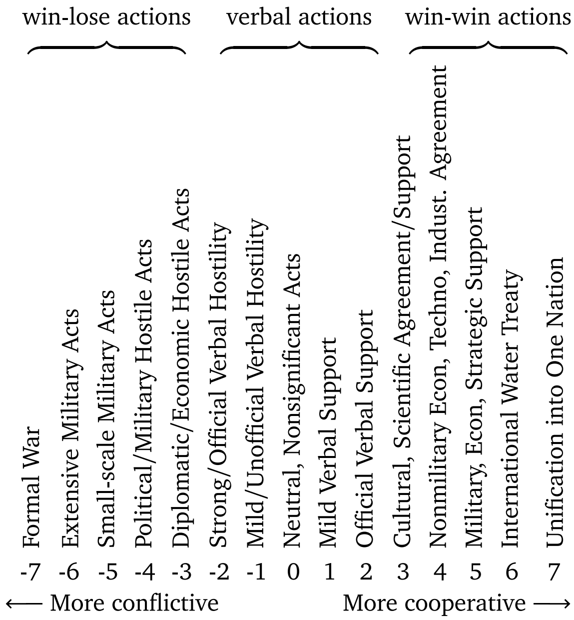


**Fig. 1.** Instances of conflict and cooperation over water resources.
*Source:* Adapted from Wolf [7].

and a post-treaty transboundary conflict [16]. Afghanistan continues unilateral utilization of Helmand River Basin waters, so either applying military, economic, or political pressure from Iran or providing incentives by Iran and Turkmenistan are expected. Iran needs more water, while Afghanistan asks for development assistance and unconditional access to the Iranian harbors on the Persian Gulf [16,17]. The water crisis in the Middle East not only has been enflaming regional and social tensions, but also has humanitarian consequences, such as when several villages in Iran were evacuated for lack of water. At the same time, many big cities experienced demonstrations and conflicts among stakeholders due to severe water rationing and resulting economic losses and public health damages [18]. Three thousand years ago, the Iranian civilization invented qanats, directing snowmelts through hand-dug underground tunnels. Earlier than many countries, it also developed the tallest arch dam of the world, flood control works (e.g., Nahrawan complex east of Tigris), water mills [18,19], and an ethical system of channels for ensuring water availability to all while considering the desert ecological climate (its latest version attributed to the Safavid minister Shaykh Baha'i). However, in the face of increasing population and socioeconomic growth, Iran now faces water depletion and dust storms due to the damming of rivers, pumping of groundwater, making short-sighted development decisions, and mismanaging water resources, as well as degrading the value of the ecosystem in devising the policies [18]. Economic growth and urbanization also impact environmental sustainability [20]. Many areas of Iran experience intra- and inter-border drought and scarcity problems among several beneficiaries, including human ecology. Transboundary and national plans are required, under the ecological constraints imposed by Iran's arid climate [18].

#### *1.1.1. Related concepts*

In computer science, economics, and psychology, negotiation is the science and art [21] of settling a dispute. While negotiating parties competitively desire to increase their own profit, they exchange offers following the rules of encounter and cooperate to reach a mutually beneficial agreement [22]. This does not happen easily or may burden many efforts by increasing the exchange of offers between the negotiators due to a lack of knowledge about the private preferences of each party as well as the vast number of possible options to consider: situations that are difficult for humans to tackle. The very dynamic and changing nature of negotiation and the diverse ranges of alternatives among several parties make it a complex and challenging process to assess in different situations.

Moreover, it is worth noting that "No development can be sustainable without including culture", especially the sustainable use of environmental resources as emphasized by the United Nations 2030 Agenda on the role of cultural dimensions in sustainable development [23]. This is in addition to the cultural adaptation of societies to climate change [24]. Culture and the cultural perception of the environment matter [25]; obtaining detailed information about cultures can reveal their similarities and differences, as well as how they might adapt to other cultures, which helps us to understand personal motivations [26,27]. Cultural parameters do affect the parties' decision-making processes and add to the complexity.

Artificial Intelligence (AI) introduces different kinds of solutions to environmental sustainability [28]. Specifically, intelligent agent technology [29–31] provides the capabilities of intelligent software systems (agents) to operate on behalf of humans in highly complex or tiresome repetitive procedures in ultra-large decision-making domains. Intelligent agents can autonomously elaborate problem-solving behaviors in distributed environments without the intervention of human users [31–35].

Culturally differentiated agents have already been used as models for "bilateral negotiations" in an agent-based marketplace [36,37]. Multilateral diplomacy improves environmental quality [38]. Sustainable development adaptation to climate change is an unstructured problem, and it causes complexities in implementing negotiations that consider multiple issues and multiple stakeholders. Multiparty negotiation to manage complex water challenges identifies and involves stakeholders, decision factors, and alternatives [39].

#### *1.1.2. Contribution of the study*

Herein we present a sustainable culture-based multilateral automated negotiation among agents representing the stakeholders in conflict over the management of water resources. As opposed to game-theoretical approaches to collective water resources management (e.g., [40]), the parties have no information about the preferences of each other regarding the solution space in actual cases. In the absence of such information, culture provides a clue about the other parties. This study is not conducted using surveys or data to prescribe the results, but by considering culture in resolving conflicts among stakeholders in a water resources management problem. It advances the state-of-the-art for management of environmental resources by investigating a sustainable automated negotiation approach applying cultural factors in a multiparty scenario. To create a win–win result, each party offers the best among all jointly acceptable alternatives, and the parties must learn the needed information about the other parties through a few exchanged offers. This helps the parties to avoid exchanging offers that are not mutually beneficial, which results in fewer failures in time-limited, real negotiations.

To this end, we first exploit cultural parameters in recognizing the criteria and decision alternatives in an environmental case study involving the management of water resources [41,42]. Next, using implicit cultural data and without the intervention of the stakeholders, which includes 'nature' as a stakeholder, we elicit preferences of the parties regarding the criteria using a multi-criteria decision-making (MCDM) method. By employing this information and social choice methods, we prune the outcome space to a limited set of feasible alternatives. Finally, by an $(m+1)$-ary negotiation among $m$ stakeholders and 'nature', again based on culture, we not only reduce the time and the number of rounds taken in gaining the outcome, but also autonomously determine the agreement: the most possible sustainable treaty. We propose an approach combining a multi-criteria decision-making method for ordinal preferences (TOPSIS) and an ordinal social choice method (Most Pleasure) into multilateral automated negotiation components. It is

**Table 1**
Cultural factors impacting negotiations [43].

| Factor | Range | | |
|---|---|---|---|
| Goal | Contract | ⟷ | Relationship |
| Attitude | Win–win | ⟷ | Win–lose |
| Personal style | Formal | ⟷ | Informal |
| Communication | Direct | ⟷ | Indirect |
| Time sensitivity | High | ⟷ | Low |
| Emotionalism | High | ⟷ | Low |
| Form of Agreement | General | ⟷ | Specific |
| Building an Agreement | Top-down | ⟷ | Bottom-up |
| Team Organization | One Leader | ⟷ | Group Consensus |
| Risk Taking | High | ⟷ | Low |

**Table 2**
Five cultural negotiation parameters in twelve countries [43].

| Parameter(%) | Country | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spain | France | Brazil | Japan | USA | Germany | UK | Nigeria | Argentina | China | Mexico | India |
| The goal of negotiation (contract) | 74 | 70 | 67 | 55 | 54 | 54 | 47 | 47 | 46 | 45 | 42 | 33 |
| Win–win attitude | 37 | 80 | 44 | 100 | 71 | 55 | 59 | 47 | 81 | 82 | 50 | 78 |
| Low time sensitivity | 21 | 40 | 0 | 9 | 15 | 36 | 6 | 7 | 15 | 9 | 33 | 44 |
| General form of agreement | 16 | 30 | 22 | 46 | 22 | 45 | 11 | 20 | 27 | 27 | 17 | 44 |
| High risk | 47 | 90 | 56 | 18 | 78 | 72 | 88 | 73 | 73 | 82 | 50 | 89 |

helpful as a sustainable cross-cultural negotiation support system in multilateral water challenges and could be extended in several dimensions: adapting to other factors specific to case studies, employing real data related to case studies, and adapting to case-specific ordering and decision-making methods.

### 1.2. Organization of the paper

After this introduction, Section 2 reviews the related concepts in automated negotiation and culture. The contribution of the paper, the sustainable automated treaty, is presented in Section 3, where the criteria for water resources management based on cultural factors are introduced by reproducible calculations. Automatic elicitation of the stakeholders' preferences and automatic determination of general and specific treaties are presented in Section 3.1–Section 3.4, respectively. After demonstrating the findings in Section 4, Section 5 concludes and suggests future works.

## 2. Culture and e-negotiation

Negotiation is a branch of artificial intelligence that simultaneously suffers from vast and rare data. Finding what to offer or accept among the massive space of all possible options with no prior information about the acceptability of offers for a counterparty in parallel to real-time learning about the opposing parties using only a few offers exchanged, are both complex for humans and machines to deal with. In economics, negotiation occurs when one has what you need, and you would like to bargain for gaining it, and vice versa [44]. Two or more entities negotiate on shared resources, and each one seeks to gain these resources. Negotiation can be automated and run [45,46] by the contemporary technology of intelligent software agents, which can represent humans and be more rapid in their conduct, generally according to an alternating offer protocol [47]:the first party gives the opponent his/her desirable offer proportional to the maximum expected utility, the opponent receives the offer and then follows in three ways: accepts the offer, or makes a change and sends a desired counter-offer to the first party, or rejects the offer. The negotiating parties are unaware of each other's utility threshold and function while trying to submit an offer as close as possible to the offer made by the opponent. If, during the negotiations, either of the parties does not see the potential of gaining more profit, no agreement is reached, and that is the end of the negotiation.

One of the most challenging problems in negotiations over environmental resources is the relevant understanding the parties have of each other, especially the principles (rules, obligations) they use in the negotiations, and their culture [48]. Culture is a broad concept [49]. Hogan describes culture as a set of values, principles, and norms accepted by a group of people [50]. Northouse addresses culture as a set of beliefs, rules, principles, norms, signs, and traditions shared by a group [51]. Hofstede believes that culture is multilayered, where the surface encompasses dress, language, food, etc., but the inner layers, which are related to the principles and values of a society, are the key to success in interactions with other cultures [52].

Salacuse treats culture as a set of social behaviors, patterns, principles, beliefs, and values transferred in society [43,53]. Moreover, he presented the following ten factors to demonstrate the impact of cultural differences during negotiations: goal, attitude, personal style, communication, time sensitivity, emotionalism, the form of agreement, building an agreement, team organization, and risk-taking, together with statistical data for several countries [43], Table 1. It constitutes the basis for this study.

The goal of a negotiator can be making either a contract or a (long-term) relationship. The opponents in each negotiation process have different attitudes, which can be either win–win or win–lose. Individuals with a formal style avoid discussing personal issues, while informal individuals attempt to make friendly relationships. Some cultures value simple and direct communication, while others prefer indirect contact, including rhetoric, facial gestures, and body movements. Sometimes people have higher time sensitivity and like to negotiate in a short time to reach a rapid agreement, and sometimes they like to negotiate for a long time with a long-term agreement. Individuals from certain cultures show their emotions while negotiating. Others, however, tend to hide those emotions by blocking facial cues and remaining calm. Another cultural factor is the form of agreement in which the opponents sometimes pursue detailed specifications, negotiation conditions, and probable agreement and sometimes pursue general issues without any care about the details. While some cultures focus on the individual and prefer a single leader with complete authority to make decisions, others consider groups more important. High-risk people do not care about a guarantee in negotiation, while low-risk people pursue guarantees and sponsorship to ensure the negotiation process. This attribute can impact each party's willingness to disclose information or accept uncertainty [43] (Table 2).

Here, we map several cultural factors to criteria, alternatives, and preferences for water management resources. Automated negotiation has been modeled well in water resources management at a fine-grained level [54–57], where the stakeholders negotiate over detailed values of specific problem attributes. However, we present a model for the coarse-grained level of the problem so that those existing models can be integrated after its final phase (cf. Example 3).

## 3. Sustainable automated negotiation

In sustainable negotiation over water resources, there are two concerns: (1) managing both water quantity and water quality for allocations for multiple uses among parties with different or opposing preferences, and (2) the need for protecting the environment. In addition to the parties' preferences over many issues, the culture of the parties also plays an important role in such conflicts and negotiations. The objective of this study is to address such a typical complex conflict on water resources through culture-based automated negotiation among stakeholder countries. To this end, in addition to the parties in the conflict, another decision-maker, 'nature', is also considered in the negotiations. That is, it makes any bilateral negotiation a trilateral one

**Table 3**
Decision criteria for cross-cultural negotiation on sustainable water resources management based on Salacuse's cultural factors.

| Criterion | Description |
|---|---|
| $C_1$ (goal) | Ranges from "0" (consumptive use) to "1" (sustainable use), adapting the theories and principles concerning shared water resources management; principles respecting sustainability: Limited Territory Integrity, Limited Territorial Sovereignty, Equitable Utilization; principles address consumptions: Absolute Territorial Sovereignty, Absolute Territorial Integrity |
| $C_2$ (attitude) | Ranges from "0" (win–lose) to "2" (win–win) based on taking very competitive to very cooperative actions regarding shared water resources as listed in Fig. 1 |
| $C_3$ (time sensitivity) | Any modification not disadvantaging an excluded stakeholder party is possible before binding the joint enforceable agreement; the time to commitment ranges from "0" months (immediately, as is) to "20" months |
| $C_4$ (form of agreement) | The specifications and the number of issues under negotiation varies from "0" (no details) to "5" issues including local usage (domestic, irrigation, industrial, navigation, forest, and land use); socio-environmental concern (water quality control, flood control, drainage and used water disposal, protection of threatened, endangered and rare species, mitigating climate change); sustainable development (hydropower energy, water reservoir, storage, canal); joint cultural/financial/technological ventures for water production and optimum exploitation of water resources; integrated water resources planning and monitoring |
| $C_5$ (risk taking) | Monitoring ecological, forestry, and patterns of harvest data regarding water demand (local and aggregated usages) and water supply (watercourse, rain, interbasin transfer, groundwater, wastewater recharge), ranges from "0" (no monitoring) to "12" (monthly monitoring) |

and $m$-ary negotiation a multilateral negotiation among $m+1$ parties. Preferences of nature, i.e., the party responsible for preserving the environment, must be met and satisfied as 'required specifications' in any joint decision.

### 3.1. Criteria and alternatives

Multi-criteria decision-making has been considered in real-world water research. Different numbers and kinds of criteria and alternatives have been introduced in the literature for shared water resources management so that no unique set of parameters exists. By classifying the parameters and values described in the literature [4,7,57–69] and adapting to the cultural factors in Table 1, we defined the criteria illustrated in Table 3. For example, when a party values a solution for its own territorial integrity, it ignores not only other parties, but also the global environment. Accordingly, this does not lead to a sustainable result: the code "0" goal.

The *goal* ($C_1$) depends on the employed theory [70]. Theories that give the authority to one side of the negotiation, so would ignore 'nature', are not sustainable. *Attitude* ($C_2$) varies from win–lose to win–win actions in Fig. 1. The high *time sensitivity* ($C_3$) of a party puts that country in urgent need to harvest the result of the negotiation soon, while patient negotiators may still deliberate and request modifications. At the same time, it considers the advantages of all stakeholders. The main part of the negotiation develops using the *form of agreement* ($C_4$),

**Table 4**
Description of the alternatives in water resources management.

| Alternative | Description of the solution for... |
|---|---|
| $A_1$ | Sustainable use, a win–win action, committing within 3 months, specifications on 1 issue, with 3 months of monitoring per year |
| $A_2$ | Consumption use, a win–win action, committing within 5 months, specifications on 5 issues, with 6 months of monitoring per year |
| $A_3$ | Sustainable use, a neutral action, committing within 7 months, specifications on 2 issues, with 12 months of monitoring per year |
| $A_4$ | Sustainable use, a win–lose action, committing within 20 months, specifications on 3 issues, with 12 months of monitoring per year |
| $A_5$ | Consumption use, a neutral action, committing within 15 months, specifications on 5 issues, no monitoring per year |
| $A_6$ | Sustainable use, a neutral action, committing within 4 months, specifications on no issues, with 6 months of monitoring per year |

including negotiation issues and values such as the 'usage' type, 'socio-environmental' concerns, 'sustainable development', 'joint ventures', and 'integrated planning'. *Risk-taking* ($C_5$) of a party could translate into the trust in executing the procedure, so that risk-prone ones would not need to gain information on water supply and utilization. Still, the low-risk parties would need to monitor monthly.

This yields $2 \times 3 \times 21 \times 6 \times 13 = 9,828$ possible outcomes (still, coarse-grained alternatives; the fine-grained at the-middle level, Section 3.4.1), too many to exchange in practice, showing the need for using an automated version of negotiation for solving the problem. To represent this in a computational case, without loss of generality, we assume even a limited feasible subset of the alternatives could be considered for negotiation, as described in Table 4 for six.

The range for any parameter's values could be decreased or increased depending on the actual case study. For example, the number of monitorings that describe the risk-taking level of the parties could span several years or decades, or even forever.

### 3.2. Automatic elicitation of preferences without the intervention of stakeholders

We employ an MCDM approach for eliciting stakeholders' preferences regarding criteria for the shared water resources management problem. The priority of alternatives for each party is measured based on their proximity to the criteria. Using The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [71], the cultural data about stakeholders are included to cover their preferences over the alternatives without their intervention. One of the advantages of this method is that all criteria and indices used for the comparison process can possess different scale units to show a positive or negative nature. The decision matrix made by the numerical values of all possible alternatives of Table 4 based on the criteria of Table 3 is shared among all participants, Table 5. However, each alternative is weighted differently for each stakeholder based on their culture.

For example, the weight factors from Table 2 for France are $\{70, 80, 40, 30, 90\}$. Since more than 70% of people aim to "contract" in France, and the representing factor for the "aim of contract" is defined as the "sustainable use" factor in the model, we put the value of 30% in the weight matrix for $C_1$. This means that 30% of French people make negotiations to "contract". Increasing this percentage

**Table 5**
The available decision alternatives.

| Alternative | Criterion | | | | | Cost |
|---|---|---|---|---|---|---|
| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | |
| $A_1$ | 1 | 2 | 3 | 1 | 3 | 1800 |
| $A_2$ | 0 | 2 | 5 | 5 | 6 | 1200 |
| $A_3$ | 1 | 1 | 7 | 2 | 12 | 2000 |
| $A_4$ | 1 | 0 | 20 | 3 | 12 | 1500 |
| $A_5$ | 0 | 1 | 15 | 5 | 0 | 700 |
| $A_6$ | 1 | 1 | 4 | 0 | 6 | 1500 |

**Table 6**
The weight of factors for France.

| | Criterion | | | | |
|---|---|---|---|---|---|
| Index | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
| Influence | positive | positive | negative | positive | negative |
| Weight | 0.30 | 0.80 | 0.60 | 0.70 | 0.90 |

**Table 7**
Distance of alternatives to the positive and negative ideals, and to the ideal solution for France.

| Alternative | Distance to positive ideal | Distance to negative ideal | Closeness to the ideal alternative |
|---|---|---|---|
| $A_1$ | 0.377 | 0.764 | 0.67 |
| $A_2$ | 0.322 | 0.784 | 0.709 |
| $A_3$ | 0.671 | 0.442 | 0.397 |
| $A_4$ | 0.85 | 0.302 | 0.262 |
| $A_5$ | 0.389 | 0.761 | 0.662 |
| $A_6$ | 0.573 | 0.536 | 0.483 |

shows that more people consider this factor a positive characteristic. Survey results by Salacuse in France show that: 80% of participants have win–win attitudes; 40% low-time sensitivity (i.e., 60% of participants are concerned about the short time to commit) is considered a negative characteristic, where increasing the percentage means higher sensitivity to the commitment time; the specifications are important for 70%, which reveals the importance of a detailed contract for them and defined as a positive characteristic, $C_4$ (the values in Table 2 indicate the general form of the agreement but not detailed), the risk is 90% indicating a negative characteristic, since higher risk leads to lower monitoring costs. The weight of 5-factors for France is then given in Table 6. The parameters $C_3$ and $C_5$ are negative criteria, indicating the minimum value for them is the positive ideal solution, and the maximum value is then the negative ideal solution.

Through the multiplication of the weights and normalized decision matrices (cf. Appendix A for the details), the distance of each alternative to the positive and negative ideals, as well as the relative proximity of each alternative to the ideal solution (closer to the positive matrix, farther from the negative matrix) for French participants is then calculated as Table 7. That is, French participants order the alternatives as Eq. (1), where $\succ$ describes the preference relation [72,73] between two alternatives, so that $A_2$ and $A_4$ are respectively the most preferred and least preferred alternatives for France:

$$A_2 \succ A_1 \succ A_5 \succ A_6 \succ A_3 \succ A_4 \tag{1}$$

In the same way, the preferences of participants from other countries are also calculated as shown in Table 8. It is a contribution gained by using Salacuse's cultural factors.

### 3.3. Automatic general treaty among stakeholders using social choice

We use computational social choice to designate one 'general' agreement among several parties. Social choice theory determines the alternative having the highest rank among the group members' preferences. The score of each alternative $A_i$ is $score(A_i) = (n+1) - rank(A_i), i = 1, \ldots, n$, where $n$ is the total number of alternatives and $rank()$ gives

**Table 8**
The obtained priority of alternatives for 12 countries.

| Alternative | Country | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spain | France | Brazil | Japan | USA | Germany | UK | Nigeria | Argentina | China | Mexico | India |
| $A_1$ | 2 | 2 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 1 | 2 | 1 |
| $A_2$ | 5 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 |
| $A_3$ | 1 | 5 | 3 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| $A_4$ | 3 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| $A_5$ | 6 | 3 | 5 | 5 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| $A_6$ | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

**Table 9**
The 'most pleasured' alternative(s) in multilateral negotiation on water resources management.

| Stakeholder | Alternative | | | | | |
|---|---|---|---|---|---|---|
| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ |
| France | 5 | 6 | 2 | 1 | 4 | 3 |
| Germany | 6 | 5 | 2 | 1 | 4 | 3 |
| NATURE | 5 | 6 | 2 | 4 | 1 | 3 |
| Max score | 6 | 6 | 2 | 4 | 4 | 3 |
| *Most Pleasure solution(s)* | $\mathbf{A^* = A_1}$ **or** $\mathbf{A_2}$ | | | | | |

the alternative rank in the ordinal preferences. There are different social choice methods for aggregating the alternatives' scores (i.e., for obtaining a single ordered preference of the group), each given by a party. Group TOPSIS using Borda has already been considered in the robot selection problem [74]. However, it has been shown that Borda is the least precise, while *most pleasure* and *approval* are the most precise methods in meeting (different kinds of) preferences of the group members [75]. In a *most pleasure* strategy, per each item, the maximum vote given by group members represents the aggregated score of the item, Eq. (2). The *approval* strategy assumes a threshold, and the total number of members who gave scores above the threshold is counted per each item. Due to criticisms of the approval method [72], we use 'most pleasure', $A^*$, and the most pleasured alternative is defined in Eq. (2).

$$A^*_{most\,Pleasure} = \underset{i=1,\ldots,n}{\operatorname{argmax}}\ score(A_i) \tag{2}$$

**Example 1.** Assume there is a conflict over shared water resources among two countries, $R$ and $S$. To be sustainable, any solution must take environmental concerns into account. Therefore, the preferences of 'nature', here a legal party considering the environmental needs, are also included in the decisions. Due to the lack of such collected data, without loss of generality, we assume that the culture and preferences of 'nature' are respectively like the data for Mexico (a semi-arid country, or Brazil, a green country, or any other different preferences) in Tables 2 and 8. Again, without loss of generality and since cultural data for two neighboring countries with shared water resources [76–78] are available, we assume $R = France$ and $S = Germany$ (conflicting over the Rhine River). According to the 'most pleasure' social choice using Eq. (2), the general solution $A^*$ is illustrated in Table 9, where the highest rank alternative (i.e., $rank = 1$) has the highest score (i.e., $score = n$), and is thus the general solution, i.e., $A_1$ or $A_2$.

That is, by considering the cultural factors of the stakeholders, we could implicitly prune the solution space and determine a general treaty without the involvement of any mediator [67] and before starting any interaction.

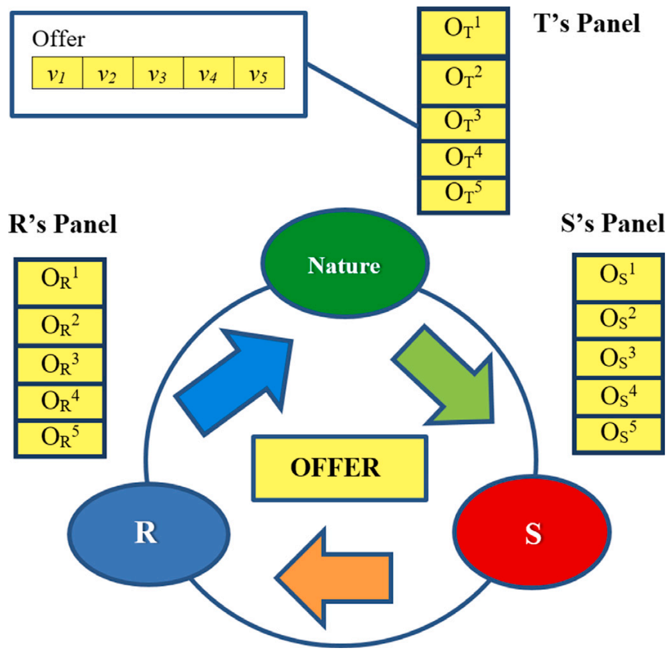


**Fig. 2.** The multi-attribute panels of each agent and the general scheme of a multilateral negotiation.

### 3.4. Automatic specific treaty among stakeholders using multilateral negotiation

To obtain the specific solution that illustrates the issues, an agent-based multilateral multi-attribute e-negotiation over the 'most pleasured' general agreement $A^*$ regarding water resources management among several countries is presented, in which the risk parameter related to their culture is taken into account. Risk-taking is an important parameter attributed to personalities that has been addressed in several pieces of research in bilateral negotiations [79]. Risk can be considered as the probability of not accomplishing a prediction or the probability of lack of success in implementing a decision. Consequently, some cultures have made advances in this respect and can encounter risk and tolerate the consequences; some cultures prefer to follow consistent measures and avoid the trial of new concepts and adventures.

The multilateral e-negotiation over details of the 'most pleasured' general agreement (e.g., $A_2$ or $A_1$ in Table 4 of Example 1 among France, Germany, and 'nature' and in a trilateral negotiation) is of the multilateral protocol [80], where every agent negotiates without being aware of the preferences and strategies of the other(s). Every negotiation turn is assigned clockwise to one agent's offers, as presented in Fig. 2. The first agent begins the session with an offer, immediately observable by the other two agents. Upon receiving an offer, the next agent can resort to making a counter-offer (which can mean rejection of the previous offer), accepting the offer, or leaving the session. This pattern is repeated until an agreement is reached or the time is over. Acceptance of an agreement means all parties are in favor of the proposed offer by all parties. It is obvious that if by the end of the negotiations, an agreement is not reached, the whole negotiation is a failure.

Some kinds of negotiations among multiple parties have been modeled using real data in several types of investigations where they address group recommendations, that is, by collecting and aggregating all the rate scores [81]. However, it is different from the case here, in which evaluating and rating all outcomes, even in this high-level phase, is impossible or complex, but negotiation strategies select promising alternatives (among all those in the outcome space) to exchange in a multilateral negotiation.

**Table 10**
The attribute values (from 'form of agreement', $C_4$ in Table 3) in trilateral negotiation in water resources management.

| Issue | Value code | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| 1: Local usage | Domestic | Irrigation | Industrial |
| 2: Socio-environmental concern | Water quality | Flood control | Wastewater disposal |
| 3: Sustainable development | Hydropower energy | Watercourse reservoir | Watercourse canal |
| v4: Joint ventures | Training people | Modification of water production & extraction technological structure | Protecting land, forests, and rare species |
| 5: Integrated monitoring | Monitoring impact of climate change | Evaluating water quantity & quality | Monitoring utilization & conservation |

#### 3.4.1. Attribute values of stakeholders' utility spaces

The negotiation is over multiple issues, constituting $C_4$ in Table 3. The negotiation issues consist of 'local usage', 'socio-environmental concern', 'sustainable development', 'joint ventures', and 'integrated monitoring', with each of these $t$ attributes comprising $l$ values, Table 10.

**Example 2.** France, Germany, and 'nature' know their own preferences regarding each possible offer in the outcome space of the problem in Example 1. Actually, they can demonstrate their preferences using any private function, such as any arbitrary linear, quasi-linear, or nonlinear function [45]. Of course, the shape of the functions affects the possibility of reaching an agreement [82]; if no shared solution is available, no agreement would be found with or without employing cultural factors. Considering cultural factors only expedites negotiations and makes the mutually beneficial agreement possible by helping the parties negotiate over the set of promising solutions in the limited available time; they fail to reach a win–win agreement, or an agreement at all. Without loss of generality, we assume different random (re-)ordering over $z = 3^5$ outcomes (of $t = 5$ issues, each with $l = 3$ values) based on the utility function in Eq. (3) (i.e., no specific concave or convex function over the domain), where $c \in \{R, S, T\}$ is the ID code of the stakeholder agent ($R$, $S$, and $T$ respectively for France, Germany and 'nature'), $offer$ is an outcome, and $Preferences^c$ is the given list of total outcomes.

$$utility^c(offer) = (z - \text{index of the offer in } Preferences^c)/z \tag{3}$$

This function is not designed to create any decision rule for the system, but to simulate the answers of real-life decision-makers. The utility function determines the evaluation $\in [0, 1]$ of an outcome for the agent. At the beginning of the negotiation, the preference of each one of the agents is formed as a combination of $l^t = 3^5$ negotiable issue values given in a 2-dimensional matrix. To generate agents' preferences differently, every row of this array is produced as a separate offer randomly in a non-repetitive sense. Here, it is assumed that the highest offer is of the most benefit. Knowing the total number of alternatives (i.e, 243), the utility of each one is calculated according to the position of the given offer in the table. The specific position of outcomes in the preferences array is private information for each agent.

In the case of a contract, social welfare is measured by the average of the individual utilities of the participating parties, Eq. (4),

$$\text{Social utility}(offer) = \frac{1}{|C|}\sum_{c \in C} utility^c(offer) \tag{4}$$

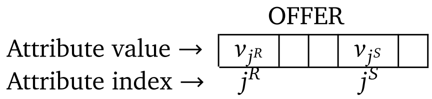


**Fig. 3.** Generating next offer of $T$ against $S$ and $R$.

where, $C$ is the set of stakeholders, here $\{T, R, S\}$, and $utility^c$ of party $c$ yields from the $offer$ (here, through Eq. (3)).

When the solution space is too large, a complete ranking of all possible alternatives might not be practical due to user burden or computational limitations. In such cases, efficient AI methods such as Iterative Deepening Search [83] or active learning to elicit user preferences by asking the least number of questions so as to not bother the human user [84] are helpful (cf. Section 5).

### 3.4.2. Negotiation strategy of stakeholders

The negotiating agents' strategy consists of three components, 'Bidding Strategy', 'Opponent-Model', and 'Acceptance Strategy' [85]. The Bidding Strategy decides which offer should be presented to the agent to be submitted to the opponent. The Opponent-Model, upon receiving the offers from an opponent, constitutes a model of the opponent's preferences (i.e., learns the opponent's preferences) that can be applied in revising its own next offer. Opponent modeling positively affects the utilities of the agents [86]. Acceptance of an offer put in by the opponent is determined based on information such as the offer ready to be submitted next and the features of the negotiating atmosphere, which includes the agent itself.

*Opponent model.* The negotiating agents of Example 2 apply $k$ last received offers for modeling their respective parties' preference. The offers are inserted in $T$, $S$, and $R$ panels separately and exposed to the partners, Fig. 2, in which each offer comprises one value per each attribute, where the values domains adopt Table 10. Each panel is cyclic, that is, beginning step $k+1$, to update the panel, the recent offer replaces the oldest one. Changes in each panel board are assessed to determine which attribute with its value (worth) for the opponent. The importance of this attribute is determined based on the number of times $f$ the offer and its specific value $v$ have been emphasized by the given agent. That is, in the previous rounds, this attribute has been subject to change less than others, and in a sense, is a Frequency-Based Model [87,88]. Considering the multi-issue structure of the offers in the panels of Fig. 2, using $k$ (e.g., five) previous offers made by $c \in \{S, T, R\}$, a typical $(v, f)$ are calculated through Eq. (5), where, $f_i$ is the frequency of value $v_i$ with the highest occurrence in the column with the $a_j$ attribute.

$$(v_i, f_i) = (\underset{(j=1,\ldots,t)}{\text{argmax}_j} count(a_i, v), \max(\underset{(v=1,\ldots,l)}{count_v}(a_i, v))) \tag{5}$$

Following this, the most important attribute and its value are derived based on the agents' previous offer, that is $(i, v) = (p, v_p)$, where $p = \text{argmax}_{1\le j\le t} f_j$ (in Fig. 3, $p$ is $j^R$ and $j^S$ for countries $R$ and $S$ respectively with corresponding values $v_{j^R}$ and $v_{j^S}$ for $v_p$). Next, among all attributes, the obtained highest frequency, the corresponding attribute, and its value are determined.

*Bidding strategy.* In the first $k$ rounds, where the panels are being filled and no agent has any model from its opponents, the bidding strategy of every agent is based on $k$ top profitable offers in its preference (sorted decreasing in the utility). From the $(k+1)$-th round on, where the panels are completely filled up, by applying the opponent model, attribute $j^R$ with the highest frequency of value $v^R$ for country $R$ and attribute $j^S$ with the highest frequency of value $v^S$ for country $S$ are determined, where $Preferences^R(i^R, j^R) = v_{j^R}; Preferences^S(i^S, j^S) = v_{j^S}$. The values $v_{j^S}$ and $v_{j^R}$ for attributes $j^R$ and $j^S$ (Fig. 3) are applied in devising the next offer by $T$, according to

$$offer^T_{next}(j) = v_j \tag{6}$$

where, $j \in \{j^R, j^S\}$. If $j^S = j^R$, the value $v$ for attribute $j = j^R = j^S$ is considered from the first visited panel. The values of other attributes are adopted from the upper rows in preference of $c$ that satisfy both conditions in order to revise the next offer.

*Acceptance strategy.* Among the three components, in this strategy, the risk-taking factor in culture is modeled in this study. A stakeholder with high risk is tempted to assess even an offer that is not of high profitability and accepts new offers at ease. Drawing decisions by $c$ on a received $offer$, i.e., the answer of '$Accept^c(offer)$?', is modeled according to the risk-taking range in Table 2 and the acceptable utility threshold of all parties, where it is 'yes' for France, Germany, and 'nature', if $r \ge 0.9$ & $u > 0.4$, or if $0.7 < r < 0.9$ & $u > 0.5$, or if $0.5 < r < 0.7$ & $u > 0.7$, respectively; 'no', otherwise. The ranges employed through this modeling adapted from Table 2 and Fig. 2 lead to an agreement. For example, the risk-taking range is 0.5–0.7 for 'nature', thus the agent would accept offers with a profitability of more than 0.7.

**Example 3.** The multilateral negotiation over 5 issues, each with 3 negotiable values in Table 10, results in the specifications of the general agreement $A_2$ of Example 2 as illustrated in Fig. 4. The more in favor of nature, i.e., **sustainable agreement is about Alternative 1** in Table 4, where the goal is sustainable use, so adopts the Limited Territory Integrity principle, Limited Territorial Sovereignty principle, or Equitable Utilization; with the same attitude illustrated in specific solution in Fig. 4, but with 3 months to commit, 3 months of monitoring per year, and over Industrial local usage (just the first issue in the form of agreement in Fig. 4).

## 4. Findings

The presented approach was compared with the case based on a 'lack of interest' in the cultural parameters. In the former case, the high-rank offer in their private preferences is the initial offer for each country, while in the latter case, the order of offers is the same for all countries. In this case, the initial offer is chosen according to the information of offers based on the descending cost ordering in Table 5. However, in the acceptance strategy, all parties only accept the offers with the utility above 0.8. In both cases, if the opponent accepts the initial offer, then the negotiation ends in one step. Otherwise, the alternatives are proposed to the opponent according to the priority order.

Tests were performed on 20 simulation trials with different underlying utility functions and distributions of cultural values of related countries. Besides considering cultural factors in preprocessing phases before the negotiation, it was also taken into account as risk-taking in the negotiation itself. It was observed that the number of rounds without risk-taking is higher than the other one, on average. The parties reached an agreement respectively in 73.8 and 9 rounds (Proposition 1). The negotiation with and without considering the risk factor brings social welfare of 0.7499 and 0.8395, respectively. The individual utility of each stakeholder in this respect also shows an increase: Germany, 0.745 to 0.808, 'nature', 0.75 to 0.91, and France, 0.751 to 0.803 (Proposition 2), two sample runs in Appendix B. The strategy failure percentage based on the cases of with and without risk-taking is equal to 0.01% and 12%, respectively (Proposition 3), Fig. 5. The presented approach is sustainable, considers environmental concerns (Proposition 4), obtains the sustainable agreement (Example 3), and implicitly prunes the highly multidimensional outcome space before starting the negotiation (Proposition 5). Moreover, cultural factors implicitly elicit quantitative (Table 7) and qualitative preferences of stakeholders (Table 11) and deal with assessing their offers in automated negotiation (Proposition 6).

**Proposition 1.** *Considering cultural parameters significantly reduces the number of rounds in negotiations.*

| | |
|---|---|
| *Goal* | Consumption use adapting Absolute Territorial Integrity principle, or Absolute Territorial Sovereignty principle |
| *Attitude* | Win-Win action adapting Unification into one nation, International water treaty, Military, econ, strategic support, Nonmilitary econ, techno, industrial agreement, or at least Cultural, scientific agreement/support |
| *Time sensitivity* | 5 months to commitment; Any modification not disadvantaging an excluded stakeholder party is possible before binding the joint enforceable agreement |
| *Form of agreement* | 1. *Local usage*: Industrial<br>2. *Socio-environmental concern*: Water quality<br>3. *Sustainable development*: Watercourse canal<br>4. *Joint venture*: Protecting land, forests, and rare species<br>5. *Integrated monitoring*: Monitoring water utilization and conservation |
| *Risk-taking* | 6 months of monitoring per each year |

**Fig. 4.** The specific outcome of sustainable negotiation between France and Germany over $A_2$ for water resources management.

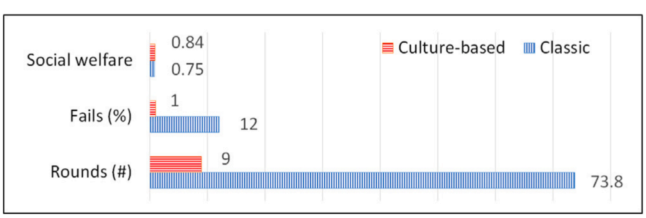


**Fig. 5.** The functionality of culture-based vs. classic trilateral negotiation between Nature, France, and Germany, in average. Higher social welfare (i.e., closer to 1), less fails percentage (closer to 0), and fewer number of rounds (i.e., closer to 1, since exchanging only one bid means a quick, successful negotiation) are preferred.

**Proposition 2.** *Considering cultural parameters improves individual utility and social welfare in negotiations.*

**Proposition 3.** *Considering cultural parameters reduces the number of failures in negotiations.*

**Proposition 4.** *The devised criteria, alternatives, attribute values,* $(m+1)$-*ary multilateral negotiation among* $m$ *stakeholders and the legal party on behalf of 'nature', and the treaty also consider environmental needs.*

**Proposition 5.** *Considering cultural parameters and the most precise aggregation method implicitly prunes the outcome space in the most appropriate, feasible, sustainable manner before starting the negotiations.*

**Table 11**
Elicited ordinal preferences of a typical user from each of twelve countries given in Table 2 over six alternatives given in Table 4.

| Country | Ordinal preference |
|---|---|
| Spain | $A_3 \succ A_1 \succ A_4 \succ A_6 \succ A_2 \succ A_5$ |
| France | $A_2 \succ A_1 \succ A_5 \succ A_6 \succ A_3 \succ A_4$ |
| Brazil | $A_1 \succ A_2 \succ A_3 \succ A_6 \succ A_5 \succ A_4$ |
| Japan | $A_2 \succ A_1 \succ A_3 \succ A_6 \succ A_5 \succ A_4$ |
| USA | $A_2 \succ A_1 \succ A_5 \succ A_6 \succ A_3 \succ A_4$ |
| Germany | $A_1 \succ A_2 \succ A_5 \succ A_6 \succ A_3 \succ A_4$ |
| UK | $A_2 \succ A_1 \succ A_5 \succ A_6 \succ A_3 \succ A_4$ |
| Nigeria | $A_2 \succ A_1 \succ A_5 \succ A_6 \succ A_3 \succ A_4$ |
| Argentina | $A_2 \succ A_1 \succ A_5 \succ A_6 \succ A_3 \succ A_4$ |
| China | $A_1 \succ A_2 \succ A_5 \succ A_6 \succ A_3 \succ A_4$ |
| Mexico | $A_2 \succ A_1 \succ A_5 \succ A_6 \succ A_3 \succ A_4$ |
| India | $A_1 \succ A_2 \succ A_5 \succ A_6 \succ A_3 \succ A_4$ |

**Proposition 6.** *Considering cultural parameters elicits the preferences of stakeholders, implicitly.*

*Generalization.* The participants do not have to be nations. For example, right now, in the southwestern parts of the USA, there is a drought that is affecting the Colorado River. Its water is used for recreation, drinking, and agriculture by several states (Colorado, Arizona, etc.), and the flow is controlled by dams: negotiation is needed, and farmers (a farming culture) have different needs than boaters (leisure culture). The same holds regarding the Zayandehrood river in the central Iranian plateau among Isfahan and its neighboring provinces, Hirmand river and Hamoon lake in the east, Urmia lake surrounded by East and West Azerbaijan provinces in the northwestern part of Iran, mismanagement of damming on the Karun River in the southwestern Khuzestan province, and several other cases. Iran is a culturally diverse society with amicable interethnic relations. Therefore, it could also benefit from the proposed approach for resolving conflicts in intra-border water challenges. The cultural preferences and needs of each stakeholder can translate into similar criteria and the approach framework. In cases, where the water basin is shared among many countries (e.g., the Danube travels within the territory of 18 nations), the approach helps limit the alternatives to consider, where non-applicable solutions are already removed from the treaty negotiations.

## 5. Conclusion and future works

Fig. 6 summarizes the contributions of the sustainable automated negotiation based on social MCDM. This study crosses four disciplines: computer science, decision science, social science, and environmental science. Adapting cultural factors in Table 2, this study collected and re-categorized criteria and issues from the water resources management literature, Tables 3, 4 and 10. The authors intuitively and conceptually classified parameters in the literature into introduced criteria and values. Another study could be done by socio-econo-environmentalists on these factors to draw the comprehensive/purified ones. The paper investigated a promising approach based on multilateral negotiation and computational social choice in resolving conflicts among countries (or states) in arid or flooded regions by considering the cultural factors of stakeholders, as well as environmental concerns. To show how the approach works, data collected by Salacuse among a few neighboring countries was employed. The implications of the presented approach are two-fold in artificial intelligence and managing environmental resources. Proposition 6 advances the state-of-the-art in eliciting the quantitative and qualitative preferences of the participants using implicit cultural information without interacting with the human user, where Table 11 is valuable for the initial offer in new encounters ([e.g., 79,89]),the personalized recommendations in applications that need information about similar interactions or users ([e.g., 90]) or learning during interactions ([e.g., 91–93]), as an educated guess in active learning to discover user's tastes for not bothering the human

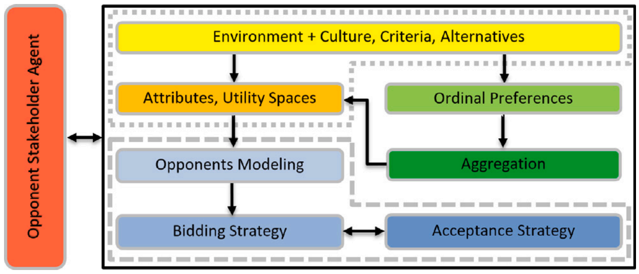


**Fig. 6.** The architecture of the agent negotiating with another stakeholder over environmental issues.

users ([e.g., 90]) in asking them questions or asking them to rank the items [84,94], and as voting data for studies in social choice and group recommendation ([e.g., 95]). The elicited information pruned the decision space before starting interactions, Proposition 5. The pruned outcome space, i.e., the specific outcome of the negotiation (Fig. 4 and Example 3), still consists of many other alternatives, where each alternative itself is now just a 'domain' in computational negotiation terms, i.e., another level of outcome spaces itself, which suggests extensions to multiple other negotiations (e.g., [55–57], and on the quantity of the local industrial usage, the measures and methods guaranteeing water quality, on planning for global ventures that focus on water scarcity or flooding, etc.). The negotiation components (Section 3.4.2 and Fig. 6) could adapt to any accurate and efficient strategies (e.g., [96–99]) in huge negotiation domains [83]. TOPSIS could be replaced with more precise approaches regarding the number of alternatives and conditional functions for the pairwise comparison between alternatives or uncertainties [60,100]. Another interesting study could develop a logical link between the components of the adapted principle goal (cf. $C_1$ in Table 3) and the feasible parameters for other criteria (in Table 3); that is, another pruning before the pruning steps in Section 3.3. The future works integrate these.

To the best of our knowledge, this is the first investigation of cross-cultural, multi-criteria and multi-issue, multilateral sustainable automated negotiation (Proposition 4). Its objective is not to prescribe the results obtained (e.g., in Fig. 4, Example 3, and Table 11), but to demonstrate the approach for conflict resolution in multiparty negotiation domains. The results can support policy-makers and stakeholders in reaching faster joint beneficial, sustainable agreements in conflicts over water, energy, climate, environmental issues, or any similar international disputes. Moreover, by following studies like those of Salacuse [43,53] and Obradovich et al. [101] for extracting cultural information through standard questionnaires or automatic manners (e.g., via social networks), such factors could be surveyed nationwide, hierarchically towards states, sectors, firms, and enterprises, hence informing the approaches of the present study. This could bring successful conclusions to the negotiations by preventing breakdowns resulting from misunderstandings or limited time.

## CRediT authorship contribution statement

**Faria Nassiri-Mofakham:** Conceptualization, Investigation, Methodology, Data curation, Visualization, Developing algorithms and examples, Formal analysis, Validation, Writing – original draft, Reviewing & editing, Funding acquisition. **Michael N. Huhns:** Validation, Writing – reviewing & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data [43] are already included in the manuscript.

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## Appendix A. Calculations

This appendix details multi-criteria decision-making in Section 3.2 based on TOPSIS where $m = 6$ options are evaluated using $n = 5$ characteristics. The logic of this method defines a positive ideal solution as well as a negative ideal solution. The positive ideal solution is that it increases the profit index and decreases the cost index. The optimum option has the least distance from the ideal solution as farther as the negative ideal solution. In other words, in TOPSIS method, the alternatives with the most proximity to the ideal solution gain higher orders in the ordering priority of options. One can then use the combinations of positive and negative indices in the TOPSIS method. Accordingly, the best option or the best solution is the nearest to the ideal solution and farthest to the negative ideal solution. This is the solution with the most profit and the least cost. The positive ideal solution can be obtained by adding the maximum values of the criteria, while the negative ideal solution can be by adding the minimum values of the criteria.

**Step 1.** *Create a decision matrix by values of alternatives based on the criteria.*

The values of alternatives order are given by the numerical variable $q_{ij}$ based on the criteria $C_1 - C_5$ for all possible alternatives $A_1 - A_6$ and from the decision-making matrix $Q$ of '6' alternatives and '5' criteria. The values of $q_{ij}$ and the components of the $Q$ matrix are given in Table 5.

**Step 2.** *Create the normalized matrix by normalizing the decision matrix entries .*

By dividing each component by the root mean square of values in the relevant column, the parameter $q_{ij}$ can be normalized using Eq. (A.1):

$$n_{ij} = \frac{q_{ij}}{\sqrt{\sum_{i=1}^{6} q_{ij}^2}} \tag{A.1}$$

For example, $n_{11} = 1/((1^2) + 0 + (1^2) + (1^2) + 0 + (1^2)) = 1/4 = 0.25$. The entries of the normalized matrix of decision making, $N$, are shown in Table A.1.

**Step 3.** *Create the weight matrix using multiplying the normalized matrix by the cultural values.*

The weight matrix of alternatives, $V$, for each country, can be obtained by the multiplication of the weight matrix, $W$, of the considered factors of the country, from Table 2, into the normalized matrix $N$. The values of the components of $v_{ij}$ can then be given by

$$V = N \cdot W = \begin{bmatrix} v_{11} & \cdots & v_{1j} & \cdots & v_{15} \\ v_{21} & \cdots & v_{2j} & \cdots & v_{25} \\ & & \vdots & & \\ v_{61} & \cdots & v_{6j} & \cdots & v_{65} \end{bmatrix}$$

$W = \{w_1, w_2, \dots, w_5\}; i = 1, 2, \dots, 6; j = 1, 2, \dots, 5$

**Table A.1**
The normalized matrix $N$ for decision alternatives.

| Alternative | Criterion | | | | |
|---|---|---|---|---|---|
| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
| $A_1$ | 0.500 | 0.603 | 0.111 | 0.125 | 0.156 |
| $A_2$ | 0.000 | 0.603 | 0.186 | 0.625 | 0.312 |
| $A_3$ | 0.500 | 0.302 | 0.260 | 0.250 | 0.625 |
| $A_4$ | 0.500 | 0.000 | 0.743 | 0.375 | 0.625 |
| $A_5$ | 0.000 | 0.302 | 0.557 | 0.625 | 0.000 |
| $A_6$ | 0.500 | 0.302 | 0.149 | 0.000 | 0.312 |

**Table A.2**
The weight matrix of alternatives for France.

| Alternative | Criterion | | | | |
|---|---|---|---|---|---|
| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
| $A_1$ | 0.15 | 0.482 | 0.067 | 0.088 | 0.14 |
| $A_2$ | 0 | 0.482 | 0.112 | 0.438 | 0.281 |
| $A_3$ | 0.15 | 0.242 | 0.156 | 0.175 | 0.562 |
| $A_4$ | 0.15 | 0 | 0.446 | 0.262 | 0.562 |
| $A_5$ | 0 | 0.242 | 0.334 | 0.438 | 0 |
| $A_6$ | 0.15 | 0.242 | 0.089 | 0 | 0.281 |

For example, the weight of five factors for France is then given in Table 6. The weight of the first factor, i.e., the aim of French participants, stands for the $(1,1)$ entry of the matrix, the weight of attitude for $(2,2)$ entry, the weight of time sensitivity for $(3,3)$ entry, and so on; the other entries are then equal to 0, as shown in Eq. (A.2):

$$\begin{bmatrix} 0.30 & 0 & 0 & 0 & 0 \\ 0 & 0.80 & 0 & 0 & 0 \\ 0 & 0 & 0.60 & 0 & 0 \\ 0 & 0 & 0 & 0.70 & 0 \\ 0 & 0 & 0 & 0 & 0.90 \end{bmatrix} \tag{A.2}$$

Thus, by multiplying the weight matrix, $W$, into the matrix $N_D$, we can obtain the weight matrix of the alternatives. Table A.2 shows the matrix for the case study in France. For other countries, the matrix, $V$, has different orders and priorities assigned to the six considered alternatives.

**Step 4.** *Obtain positive and negative ideal solutions, respectively by adding maximum and minimum values of the criteria.*

The positive and negative ideal solutions are obtained as expressed in Eq. (A.3):

$$\begin{aligned} A+ &= \{(\max_i v_{ij} | j \in J), (\min_i v_{ij} | j \in J') | i = 1,2,\dots,6\} \\ &= \{v_1^+, v_2^+, \dots, v_j^+, \dots, v_5^+\} \end{aligned}$$

$$\begin{aligned} A- &= \{(\min_i v_{ij} | j \in J), (\max_i v_{ij} | j \in J') | i = 1,2,\dots,6\} \\ &= \{v_1^-, v_2^-, \dots, v_j^-, \dots, v_5^-\} \end{aligned}$$

$$\begin{aligned} J &= \{j = 1,2,\dots,5 | j \in benefit\} \\ J' &= \{j = 1,2,\dots,5 | j \in cost\} \end{aligned} \tag{A.3}$$

The parameters $C_3$ and $C_5$ are negative criteria that indicate the minimum value for them is the positive ideal solution, and the maximum value is then the negative ideal solution. The other positive criteria reach their maximum at the positive ideal solution and vice versa. Thus, the vectors $A+$ and $A-$ are given by

$$A+ = [0.15, 0.482, 0.067, 0.438, 0]$$

$$A- = [0, 0, 0.446, 0, 0.562]$$

and the positive and ideal solutions for the French can be determined as given in Table A.3.

**Table A.3**
Calculated positive and negative ideal solutions for France.

| Criterion | Positive ideal solution | Negative ideal solution |
|---|---|---|
| $C_1$ | 0.15 | 0 |
| $C_2$ | 0.482 | 0 |
| $C_3$ | 0.067 | 0.446 |
| $C_4$ | 0.438 | 0 |
| $C_5$ | 0 | 0.562 |

**Table A.4**
The weight of factors for Germany.

| Index | Criterion | | | | |
|---|---|---|---|---|---|
| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
| Influence | positive | positive | negative | positive | negative |
| Weight | 0.46 | 0.55 | 0.64 | 0.55 | 0.72 |

**Table A.5**
The matrix of weight of alternatives for Germany.

| Alternative | Criterion | | | | |
|---|---|---|---|---|---|
| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
| $A_1$ | 0.23 | 0.332 | 0.071 | 0.069 | 0.112 |
| $A_2$ | 0 | 0.332 | 0.119 | 0.344 | 0.225 |
| $A_3$ | 0.23 | 0.166 | 0.166 | 0.138 | 0.45 |
| $A_4$ | 0.23 | 0 | 0.476 | 0.209 | 0.45 |
| $A_5$ | 0 | 0.166 | 0.356 | 0.344 | 0 |
| $A_6$ | 0.23 | 0.166 | 0.095 | 0 | 0.225 |

**Table A.6**
Calculated positive and negative ideal solutions for Germany.

| Criterion | Positive ideal solution | Negative ideal solution |
|---|---|---|
| $C_1$ | 0.23 | 0 |
| $C_2$ | 0.332 | 0 |
| $C_3$ | 0.071 | 0.476 |
| $C_4$ | 0.344 | 0 |
| $C_5$ | 0 | 0.45 |

**Table A.7**
Distance of alternatives to the positive and negative ideals, and to the ideal solution for Germany.

| Alternative | Distance to positive ideal ($D_{i+}$) | Distance to negative ideal ($D_{i-}$) | Closeness to ideal alternative ($CL_{i+}$) |
|---|---|---|---|
| $A_1$ | 0.297 | 0.668 | 0.692 |
| $A_2$ | 0.325 | 0.638 | 0.663 |
| $A_3$ | 0.531 | 0.442 | 0.454 |
| $A_4$ | 0.704 | 0.309 | 0.305 |
| $A_5$ | 0.402 | 0.602 | 0.600 |
| $A_6$ | 0.444 | 0.526 | 0.542 |

**Step 5.** *Calculate distances of alternatives to both positive and negative ideals for each stakeholder, including NATURE. Calculate the closeness of each alternative to the ideal solution (closer to the positive matrix, farther from the negative matrix) per each party.*

The distance of each alternative to the positive and negative ideals, $D$, as well as the relative proximity of each alternative to the ideal solution are defined by

$$d_{i+} = \{\sum_{j=1}^{5}(v_{ij} - v_j^+)^2\}^{0.5}; i = 1,2,\dots,6$$

$$d_{i-} = \{\sum_{j=1}^{5}(v_{ij} - v_j^-)^2\}^{0.5}; i = 1,2,\dots,6$$

The values for the France model can be calculated as follows:

$$\begin{aligned} D_{1+} = &((0.15 - 0.15)^2 + (0.482 - 0.482)^2 + (0.067 - \\ &0.067)^2 + (0.088 - 0.438)^2 + (0.14 - 0)^2)^{0.5} = 0.377 \end{aligned}$$

**Table B.1**
Sample run, 10 trilateral negotiation rounds when cultural factors involved.

| | |
|---|---|
| **Round 1** | |
| Turn1: | GERMANY's offer is<br>local usage = domestic, socio-environmental concern = water quality, sustainable development = watercourse canal, joint venture = modification of water production & extraction technological structure, integrated monitoring = monitoring utilization & conservation |
| Turn2: | NATURE's offer is<br>local usage = irrigation, socio-environmental concern = water quality, sustainable development = watercourse canal, joint venture = modification of water production & extraction technological structure, integrated monitoring = evaluating water quantity & quality |
| Turn3: | FRANCE's offer is<br>local usage = domestic, socio-environmental concern = water quality, sustainable development = watercourse canal, joint venture = training people, integrated monitoring = monitoring the impact of climate change |
| **Round 2** | |
| Turn1: | GERMANY did not accept the offer of FRANCE. ... GERMANY's offer is<br>local usage = irrigation socio-environmental concern = water quality, sustainable development = hydropower energy, joint venture = training people, integrated monitoring = monitoring utilization & conservation |
| Turn2: | NATURE did not accept the offer of GERMANY. ... NATURE's offer is<br>local usage = industrial, socio-environmental concern = water quality, sustainable development = hydropower energy, joint venture = protecting land, forests, and rare species, integrated monitoring = monitoring utilization & conservation |
| Turn3: | FRANCE did not accept the offer of NATURE. ... FRANCE's offer is<br>local usage = domestic, socio-environmental concern = flood control, sustainable development = watercourse reservoir, joint venture = modification of water production & extraction technological structure, integrated monitoring = monitoring the impact of climate change |
| | ⋮ |
| **Round 9** | |
| Turn1: | GERMANY did not accept this offer and wants a better bid. ... GERMANY's offer is<br>local usage = irrigation, socio-environmental concern = water quality, sustainable development = watercourse canal, joint venture = modification of water production & extraction technological structure, integrated monitoring = monitoring utilization & conservation |
| Turn2: | Utility of NATURE is 0.9053497942386831<br>risk of NATURE is 0.6 so<br>NATURE accepts this offer<br>local usage = irrigation, socio-environmental concern = water quality, sustainable development = watercourse canal, joint venture = modification of water production & extraction technological structure, integrated monitoring = monitoring utilization & conservation |
| Turn3: | Utility of FRANCE is 0.5596707818930041<br>risk of FRANCE is 0.9 so<br>FRANCE accepts this offer<br>local usage = irrigation, socio-environmental concern = water quality, sustainable development = watercourse canal, joint venture = modification of water production & extraction technological structure, integrated monitoring = monitoring utilization & conservation |
| **Round 10** | |
| Turn1: | Utility of GERMANY is 0.9876543209876543<br>risk of GERMANY is 0.72 so<br>GERMANY accepts this offer<br>local usage = irrigation, socio-environmental concern = water quality, sustainable development = watercourse canal, joint venture = modification of water production & extraction technological structure, integrated monitoring = monitoring utilization & conservation |
| Turn2: | Utility of NATURE is 0.9053497942386831<br>risk of NATURE is 0.6 so<br>NATURE accepts this offer<br>local usage = irrigation, socio-environmental concern=water quality, sustainable development = watercourse canal, joint venture = modification of water production & extraction technological structure, integrated monitoring = monitoring utilization & conservation |
| Turn3: | Utility of FRANCE is 0.5596707818930041<br>risk of FRANCE is 0.9 so<br>FRANCE accepts this offer<br>local usage = irrigation, socio-environmental concern = water quality, sustainable development = watercourse canal, joint venture = modification of water production & extraction technological structure, integrated monitoring = monitoring utilization & conservation |
| GERMANY utility is 0.9876543209876543<br>NATURE utility is 0.9053497942386831<br>FRANCE utility is 0.9053497942386831<br>social welfare is 0.9327846364883401<br>Negotiation is finished. After 10 rounds of negotiations with SW=0.93, the three parties agreed. | |

The closeness of alternatives ($CL$) to the ideal solution is then determined by

$$cl_{i+} = \frac{d_{i-}}{(d_{i+} + d_{i-})}; 0 \leq cl_{i+} \leq 1; i = 1, 2, \ldots, 6$$

The distance of the first alternative to the ideal solution is then calculated as

$$CL_1 = 0.764/(0.764 + 0.377) = 0.67$$

**Table B.2**
Sample run, 20 trilateral negotiation rounds when cultural factors not involved.

| | |
|---|---|
| Round 1 | |
| Turn1: | GERMANY's offer is<br>local usage=domestic, socio-environmental concern=water quality, sustainable development=watercourse canal, joint venture=modification of water production & extraction technological structure, integrated monitoring =monitoring utilization & conservation |
| Turn2: | NATURE's offer is<br>local usage =irrigation, socio-environmental concern=water quality, sustainable development=watercourse canal, joint venture=modification of water production & extraction technological structure, integrated monitoring =evaluating water quantity & quality |
| Turn3: | FRANCE's offer is<br>local usage =domestic, socio-environmental concern=water quality, sustainable development=watercourse canal, joint venture=training people, integrated monitoring =monitoring the impact of climate change |
| Round 2 | |
| Turn1: | GERMANY did not accept the offer of FRANCE. ... GERMANY's offer is<br>local usage =irrigation, socio-environmental concern=water quality, sustainable development=hydropower energy, joint venture=training people, integrated monitoring =monitoring utilization & conservation |
| Turn2: | NATURE did not accept the offer of GERMANY. ... NATURE's offer is<br>local usage =industrial, socio-environmental concern=water quality, sustainable development=hydropower energy, joint venture=protecting land, forests, and rare species, integrated monitoring =monitoring utilization &conservation |
| Turn3: | FRANCE did not accept the offer of NATURE. ... FRANCE's offer is<br>local usage =domestic, socio-environmental concern=flood control, sustainable development=watercourse reservoir, joint venture=modification of water production & extraction technological structure, integrated monitoring =monitoring the impact of climate change |
| | ⋮ |
| Round 19 | |
| Turn1: | GERMANY did not accept this offer and wants a better bid GERMANY's offer is<br>local usage =irrigation, socio-environmental concern=wastewater disposal, sustainable development=watercourse reservoir, joint venture=training people, integrated monitoring =monitoring utilization & conservation |
| Turn2: | NATURE did not accept this offer and wants offering better bid<br>NATURE's offer is<br>local usage =irrigation, socio-environmental concern=flood control, sustainable development=watercourse reservoir, joint venture=training people, integrated monitoring =monitoring utilization & conservation |
| Turn3: | FRANCE did not accept this offer and wants a better bid<br>FRANCE's offer is<br>local usage =industrial, socio-environmental concern=wastewater disposal, sustainable development=hydropower energy, joint venture=protecting land, forests, and rare species, integrated monitoring =evaluating water quantity & quality |
| Round 20 | |
| Turn1: | Utility of GERMANY is 0.7078189300411523<br>risk of GERMANY is 0.0 so<br>GERMANY accepts this offer<br>local usage =industrial, socio-environmental concern=wastewater disposal, sustainable development=hydropower energy, joint venture=protecting land, forests, and rare species, integrated monitoring =evaluating water quantity & quality |
| Turn2: | Utility of NATURE is 0.9876543209876543<br>risk of NATURE is 0.0 so<br>NATURE accepts this offer<br>local usage =industrial, socio-environmental concern=wastewater disposal, sustainable development=hydropower energy, joint venture=protecting land, forests, and rare species, integrated monitoring=evaluating water quantity & quality |
| Turn3: | Utility of FRANCE is 0.9135802469135802<br>risk of FRANCE is 0.0 so<br>FRANCE accepts this offer<br>local usage =industrial, socio-environmental concern=wastewater disposal, sustainable development=hydropower energy, joint venture=protecting land, forests, and rare species, integrated monitoring=evaluating water quantity & quality |
| GERMANY utility is 0.7078189300411523<br>NATURE utility is 0.9876543209876543<br>FRANCE utility is 0.9876543209876543<br>social welfare is 0.8943758573388202<br>Negotiation is finished. After 20 rounds of negotiations with SW=0.89, the three parties agreed. | |

The calculated distances of alternatives to the ideal solution from the French positive and negative ideal matrices are given in Table 7. Similarly, the matrices $V$ and $W$, and the parameters $D$ and $CL$ can be obtained for German participants. The results are given in

Tables A.4–A.7. That is, the order of alternatives for Germany is $A_1 \succ A_2 \succ A_5 \succ A_6 \succ A_3 \succ A_4$. Accordingly, the rank of the alternatives for twelve countries is obtained as demonstrated in Table 8.

## Appendix B. Sample runs

Tables B.1 and B.2 illustrate two sample runs of the trilateral negotiation among Germany, France, and 'nature', where the former run does and the latter does not consider cultural factors.

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