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Original Research

Evaluation Model of Environmental Governance Capacity Based on Social Network in Language Environment

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Abstract

The problem of the evaluation of environmental governance capacity is an important issue in evaluating the improvement of ecological environment and the quality of economic development, but there are few evaluation models about environmental governance capacity. Considering the expression habits, the association and the psychological changes of experts, and the ambiguity of the decision-making environment, a consensus model for group decision making of 2-dimension 2-tuple linguistic information to express decision-making information in an empathy network environment is proposed in this paper. Firstly, confidence index is built by using the 2-dimension 2-tuple linguistic information. Secondly, the empathetic centrality incorporating the confidence index is used as induced value to gather expert decision information. The group consensus level is calculated by measuring the distance between individuals and groups, and a consensus adjustment method is established by using the confidence index. Next, the 2-dimension 2-tuple linguistic weighted averaging operator is used to process the group decision information that reaches consensus and obtain the evaluation results. Finally, an example of the evaluation of environmental governance capacity is used to prove the feasibility of the model, which can provide theoretical and method support for the problem of the evaluation of environmental governance capacity.

Keywords: 2-dimension 2-tuple linguistic information, confidence index, consensus reaching, empathetic relations, group decision making

Introduction

Group decision making is the process of gathering group members' preferences for solutions into a consensus or compromised group preference order according to some rules. Group members often consist of experts in the field, but due to the differences in knowledge structure, risk preferences, and psychological changes of experts, as well as the different decision contexts of different decision problems, experts' evaluation results are often different.

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If we want to get the solution ordering that satisfies the group members, we need to make the experts come to an agreement [1, 2]. Therefore, the focus of group decision making is on how to integrate the views of multiple group members, i.e., experts, into a group view, i.e., to achieve group consensus [3-5]. A lot of research has been done on group consensus, which mainly focuses on the solution of group consensus measurement and group consensus adjustment. In terms of consensus measurement, the metrics include distance measure [6-9], similarity measure [10, 11], order measure [12], and linear programming [13], etc. The decision makers choose different metrics based on different perspectives, such as the perspective of retaining as much original information as possible, the perspective of minimizing the number of iterations [14], the perspective of considering the psychological behavior of decision makers [15, 16], and so on. In terms of consensus adjustment, the main feedback mechanisms include interactive feedback models [17], local feedback models [18, 19], social network feedback models [20], and so on. Based on different adjustment objectives, it can be classified into minimum adjustment cost orientation [21], minimum adjustment element orientation [22], minimum adjustment distance orientation [23, 24], and maximum adjustment efficiency orientation [25], etc.

In the actual group decision making process, experts are not independent of each other, and they often come from the same field. There will be phenomena such as mutual contact, mutual concern and mutual appreciation, and this social relationship will have an important impact on the decision outcome. For example, in a certain evaluation process of water pollution control capacity, expert A is the authority in the field, and then in the process of reaching consensus, other experts are more inclined to accept A's opinion. Another example is that in the decision-making process, if it is known that expert A prefers a solution, expert B may also pay more attention to that solution. The utility of an individual decision making maker regarding a decision solution depends not only on the real preferences of the individual decision making maker, but is also related to the preferences of certain other individual decision making makers in the decision group. In economics, an individual's understanding of others' emotions and concern for others' welfare is called empathy [26]. Social relationships based on empathy in group decision making are called empathetic relations, and the network formed by all empathetic relations in a group is called an empathy network [27]. Salehi-Abari et al. [28] scholars first proposed the linguistic terms, which proposed a research framework and various properties of empathetic relations. Yao Shengbao et al. [27] used intuitionistic fuzzy preference relations to express decision information, and proposed a consensus model for group decision making with the global empathetic model as a perspective. However, there are fewer studies on group decision making in the context of empathetic relations.

Considering the ambiguity of human thinking and the complexity of the decision-making environment, the expression form of linguistic phrases is more in line with the expert's cognition and close to the actual situation of group decision making decisions. Zadeh [29] first proposed the concept of linguistic variable, i.e., using linguistic phrases such as good, very good, and mediocre to express the evaluation information. Herrera [30] et al. proposed the concept of 2-tuple linguistic information on this basis, which quantifies the decision information while avoiding the loss and distortion of information. Zhu Weidong, Zhou Guangzhong and Yang Shanlin first put forward the concept of two-dimensional language evaluation information. The first dimensional information is used to express the linguistic evaluation value of the decision object and the second dimensional information is used to express the subjective credibility of the first dimensional information, which makes the expression of evaluation information more intuitive, accurate, and perfect. Therefore, in this paper, the 2-dimension 2-tuple linguistic information will be used to process the decision information.

The evaluation of environmental governance capacity is a multi-attribute group decision making problem. Its decision subject is generally the government, and the decision problem to be solved is the ordering of governance capacity. The current research on environmental governance capacity mainly focuses on influencing factors, including economic factors [32, 33], social factors [34, 35], human factors [36, 37], technical factors [38], and institutional factors [39], demographic factors [40], land use patterns [41, 42]. Some administrative units use open-source software to obtain information to solve problems [43]. However, among the current research results, there is little literature on evaluation methods.

Environmental governance capability evaluation is a systematic evaluation problem, which involves a wide range. It is difficult for evaluation experts to comprehensively master the relevant knowledge or understand the relevant information. At the same time, evaluation experts are likely affected by other experts instead of independently to make decisions. In this paper, the evaluation of environmental governance ability is regarded as a social network group decision-making problem, and a consensus model for group decision making of 2-dimension 2-tuple linguistic information under the influence of empathetic relations is constructed to solve a series of problems. Firstly, 2-dimension 2-tuple linguistic information is used to represent the decision information and describe the decision problem. Then, a consensus model for group decision making is proposed based on empathy network and confidence index. Finally, the effectiveness and feasibility of the proposed method are verified by example analysis of the evaluation of environmental governance capacity. The main contributions of this paper consist of three aspects. Firstly, the empathetic relations are extended to the field of linguistic decision making, making its application scenarios more in line with the reality of the management decision. Secondly, the psychological changes of decision makers are expressed in the form of confidence indices and combined with empathetic relations to make the decision-making process more realistic and effective. Thirdly, combining the information index with the feedback mechanism can provide as much feedback information to the experts as possible, which is convenient for them to modify the information and achieve group consensus.

Preliminaries

2-tuple Linguistic Representation Model

Definition 1 [30] $S = \{S_0, S_1, ..., S_g\}$, $S_i \in S$ is a set of linguistic terms, and then 2-tuple linguistic information can be obtained by the following function.

$$\phi : S \to S \times [-0.5, 0.5) \tag{1}$$

$$\phi : (S_i) \to (S_i, 0), S_i \in S \tag{2}$$

Definition 2 [30] $\beta \in [0, g]$ is the set of linguistic phrase evaluations; $S = \{S_0, S_1, ..., S_g\}$ is the real number obtained by a kind of set operation; and then β can be expressed as a 2-tuple linguistic information by the following function Δ.

$$\Delta : [0, g] \to S \times [-0.5, 0.5); \tag{3}$$

$$\Delta(\beta) = \begin{cases} S_i, i = round(\beta); \\ \alpha_i = \beta - i,\ \alpha_i \in [-0.5, 0.5). \end{cases} \tag{4}$$

Where round is a rounding operator.

Definition 3 [30] $S = \{S_0, S_1, ..., S_g\}$, $S_i \in S$, $\alpha_i \in [-0.5, 0.5)$, (S_i, α_i) is a 2-tuple linguistic information, then there exists an inverse function Δ^{-1} that converts it to the corresponding real number $\beta \in [0, g]$, i.e.

$$\Delta^{-1} : S \times [-0.5, 0.5) \to [0, g]; \tag{5}$$

$$\Delta^{-1}(S_i, \alpha_i) = i + \alpha_i = \beta. \tag{6}$$

Definition 4 [30] For any two 2-tuple linguistic information, the rule of comparison between them is as follows.

(1) If $i > j$, then $(S_i, \alpha_i) > (S_j, \alpha_j)$.

(2) If $i = j$, when $\alpha_i > \alpha_j$, $(S_i, \alpha_i) > (S_j, \alpha_j)$; when $\alpha_i < \alpha_j$, $(S_i, \alpha_i) < (S_j, \alpha_j)$; and when $\alpha_i = \alpha_j$, $(S_i, \alpha_i) = (S_j, \alpha_j)$.

For example, $S = \{s_0 = \textit{very poor}, s_1 = \textit{poor}, s_2 = \textit{medium}, s_3 = \textit{good}, s_4 = \textit{very good}\}$ is a 5-granularity set of linguistic terms, and then the corresponding 2-tuple linguistic information is $\Delta(2.6) = (s_3, -0.4)$ when $\beta = 2.6$. Conversely, and the value corresponding to the 2-tuple linguistic information $(s_3, -0.4)$ is $\Delta^{-1}(s_3, -0.4) = 2.6$.

2-dimension 2-tuple Linguistic Representation Model

In contrast to 2-tuple linguistic information, 2-dimension 2-tuple linguistic information uses two dimensions to express decision information. The first dimensional information represents the evaluation of the thing itself, and the second dimensional information represents the degree of certainty of the information in the first dimension.

Definition 5 [31] $S = \{s_0, s_1, ..., s_{h_1}\}$ is the set of linguistic evaluation information in the first dimension; $S^* = \{s^*_0, s^*_1, ..., s^*_{h_1}\}$ is the set of linguistic evaluation information in the second dimension, and then the 2-dimension 2-tuple linguistic information is represented as $\tilde{S}_t = ((s_{i_t}, \alpha_{i_t}), (s^*_{j_t}, \alpha^*_{j_t}))$, where $\alpha_{i_t} \in [-0.5, 0.5)$, $\alpha^*_{i_t} \in [-0.5, 0.5)$. In particular, when $\alpha_{i_t} = \alpha^*_{i_t} = 0$, $\tilde{S}_t$ degenerates to $(S_{i_t}, S^*_{j_t})$.

Definition 6 [44] If $\tilde{S}_{t_1} = ((s_{i_{t1}}, \alpha_{i_{t1}}), (s^*_{j_{t1}}, \alpha^*_{j_{t1}}))$, $\tilde{S}_{t_2} = ((s_{i_{t2}}, \alpha_{i_{t2}}), (s^*_{j_{t2}}, \alpha^*_{j_{t2}}))$,..., $\tilde{S}_{t_n} = ((s_{i_{t_n}}, \alpha_{i_{t_n}}), (s^*_{j_{t_n}}, \alpha^*_{j_{t_n}}))$ is a set of 2-dimension 2-tuple linguistic information and $\omega_t = (\omega_{t_1}, \omega_{t_2}, ..., \omega_{t_n})^T$ is its corresponding weight vector, then the weighted averaging operator is of $\omega_t = (\omega_{t_1}, \omega_{t_2}, ..., \omega_{t_n})^T$ is:

$$2DLWAA\left(\tilde{S}_{t_1}, \tilde{S}_{t_2}, \dots \tilde{S}_{t_n}\right) = \Delta\left(\sum_{q=1}^{n} \omega_{t_q} \Delta^{-1}\left(S_{i_{t_q}}, \alpha_{i_{t_q}}\right), \sum_{q=1}^{n} \omega_{t_q} \Delta^{-1}\left(S^*_{j_{t_q}}, \alpha^*_{j_{t_q}}\right)\right) \tag{7}$$

For example, $S = \{s_0 = \textit{very poor}, s_1 = \textit{poor}, s_2 = \textit{medium}, s_3 = \textit{good}, s_4 = \textit{very good}\}$ is the first-dimensional linguistic term set; $S^* = \{s^*_0 = \textit{unsure}, s^*_1 = \textit{little sure}, s^*_2 = \textit{sure}, s^*_3 = \textit{very sure}, s^*_4 = \textit{higly sure}\}$ is the second-dimensional linguistic term set, and 2-dimension 2-tuple linguistic information $\tilde{S} = ((s_3, 0.3), (s^*_3, 0.2))$ indicates that the expert has a relatively good reason to give a good evaluation.

Empathy Networks

Individuals' understanding of others' emotions and concern for others' welfare are called empathy [26]. Social relationships based on empathy in group decision making are called empathetic relations, and the network formed by all empathetic relations in a group is called an empathy network [27].

Definition 7 [27, 28] An empathy network is a directed assignment graph used to describe the empathetic relations in a group, denoted as $G(N, A)$, where $N = \{1, 2, ..., m\}$ denotes group members, $A = (a(i, j)$ denotes group member i has empathetic relations with group member j. The weight information on the directed arc is the empathy weight, whose magnitude represents the intensity of group member

i's attention to group member j. For group member e_i, the empathy weight satisfies $w_{ii}+\sum_{j\neq i} w_{ij}=1$, where w_{ii} is called the weight of group member i in adhering to personal opinion. In general, $\forall i\in N$, and therefore $w_{ii}>0$.

Definition 8 [27, 28] In an empathy network, the empathetic centrality is used to characterize the centrality of a node. In the empathy network $G(N, A)$, $\forall j\in N$, if $A(j) = \{i\neq j \mid a(i, j)\in A\}$, $EC_j = w_{jj}+\sum_{i\in A(j)} w_{ij}$ is called the empathetic centrality of node j. Obviously, the greater the empathetic centrality of a node, the more important the node is in the empathy network, and the more likely the expert opinion represented by that point is valued and accepted by other experts. Since $\forall i,\ w_{ii}+\sum_{j\neq i} w_{ij}=1, w_{ii}>0$, and $EC_j\in(0,m)$, then $\sum_{j=1}^{m} EC_j = m$.

For example, the Fig. 1 shows the empathy network in normal circumstances, where $N = \{1, 2, 3, 4\}$ is four experts, $W = (w_{ij})_{m\times m}$ denoting the empathy weight matrix.

$$W=\begin{pmatrix} 0.8 & 0.1 & 0 & 0.1 \\ 0.3 & 0.6 & 0.1 & 0 \\ 0.3 & 0 & 0.5 & 0.2 \\ 0.3 & 0.1 & 0.2 & 0.4 \end{pmatrix}$$

It is easy to see that the sum of the elements in row i of the empathy weight matrix $W = (w_{ij})_{m\times m}$ is 1, i.e. $w_{ii}+\sum_{j\neq i} w_{ij}=1$; the sum of the elements in column j is the empathetic centrality of node j. The values of empathetic centrality of the four experts in order are $EC_1 = 1.7$, $EC_2 = 0.8$, $EC_3 = 0.8$, $EC_4 = 0.7$; thus it can be seen that expert 1 is the most trusted and occupies the most important position in the decision-making process.

A Consensus Model for Group Decision Making of 2-dimension 2-tuple Linguistic Information Based on Empathetic Relations

Considering a consensus of group decision problem expressed by 2-dimension 2-tuple linguistic information, with m experts e_k ($k = 1, 2, 3, ..., m$), giving evaluation values for n alternatives x_p ($p = 1, 2, 3, ..., n$) and r attributes c_q ($q = 1, 2, 3, ..., r$). The evaluation information is expressed by 2-dimension 2-tuple linguistic information. The first dimensional 2-tuple linguistic information indicates the leave-taking of the thing itself, and the 2-tuple linguistic information providing linguistic evaluation information is $S = \{s_0, s_1, ..., s_g\}$. The second dimensional 2-tuple linguistic information indicates the degree of certainty about the first dimensional information, and the linguistic phrase providing credibility is $\dot{S}=\left\{\dot{s}_0,\dot{s}_1,\dots,\dot{s}_h\right\}$, $s^k_{u_{pq}}\in S, \dot{s}^k_{v_{pq}}\in \dot{S}$, $S=\left(\left(s^k_{u_{pq}},\alpha^k_{u_{pq}}\right),\left(\dot{s}^k_{v_{pq}},\dot{\alpha}^k_{v_{pq}}\right)\right)$ indicating a 2-tuple linguistic information, where $\alpha^k_{u_{pq}}\in[-0.5,0.5)$, $\dot{\alpha}^k_{v_{pq}}\in[-0.5,0.5)$. The 2-dimension 2-tuple linguistic information evaluation matrix provided by the expert e_k is $M_k=\left(\left(S^k_{u_{pq}},\alpha^k_{u_{pq}}\right),\left(\dot{S}^k_{v_{pq}},\dot{\alpha}^k_{v_{pq}}\right)\right)_{n\times l}$. Denote that the expert weight is $\eta = (\eta_1, \eta_2, ..., \eta_m)^T$, and the attribute weight is $\omega = (\omega_1, \omega_2, ..., \omega_r)^T$. The empathetic centrality of the expert is $EC = \{EC_1, EC_2, ..., EC_m\}$.

Due to the expert variability and the ambiguity of the decision context, an important step in the group decision process is group consistency analysis, also known as consensus analysis. The group consensus process is the process of convergence of opinions through continuous adjustment of group members' opinions [45-50]. The group decision making problem guided by empathetic relations requires consideration of the relationship between experts and the process of experts' psychological changes in the process of reaching a consensus. This section uses the empathetic centrality adjusted by confidence index as the induced value to gather the results of group decision making. Then the distance between individual decision making and group decision is calculated to derive the consensus level, and then the feedback mechanism is used to identify the most deviant value of the expert and adjust it to reach the set threshold, and finally the group decision is made on the basis of achieving consistency.

Gathering Information for Group Decision Making

One problem to consider before gathering group decision information is whether the empathetic centrality is simply the sum of the expert's self-identification weight and the empathy weight of others toward that expert. The empathetic centrality represents the importance of the node in the empathy network, and only objective factors are considered in this passive summation. But subjectively, how confident the expert is in his or her own opinion also has an impact on his or her status in the network. For example, if an expert is very confident in his or her own decisions, he or she will magnify his or her own opinions and ignore the influence of others on him or her, and the empathetic centrality of the node represented by that expert will

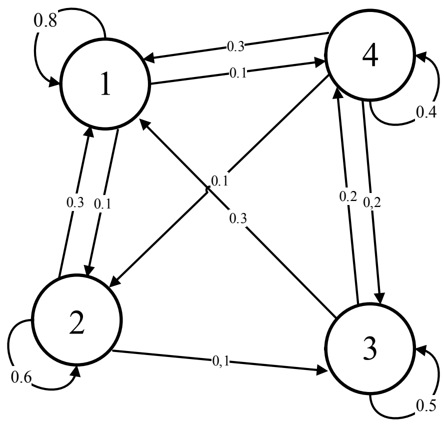

Fig. 1. Empathy network.

change. In this section, the empathetic centrality is moderated by using the confidence index.

The 2-dimension 2-tuple linguistic information is represented as $\left(\left(s^k_{u_{pq}},\alpha^k_{u_{pq}}\right),\left(s^{\dot{k}}_{v_{pq}},\alpha^{\dot{k}}_{v_{pq}}\right)\right)$; the second dimensional information indicates the degree of certainty about the information of the first dimension. The second second dimensional information is used to build the expert confidence index. Let ρ_k be a power function, which means that its utility is monotonically increasing and its first-order derivative is monotonically decreasing.

$$\rho_k = CF_k^{\gamma} = \left(\sum_{p=1}^{n}\sum_{q=1}^{l}\left(v^{\dot{k}}_{pq}+\alpha^{\dot{k}}_{pq}\right)\right)^{\gamma} \tag{8}$$

Among them, γ is the confidence coefficient ($0<\gamma<1$). Obviously, $0\le\rho_k\le1$; the larger the CF_k is, the more confident the expert e_k is in his own opinion; he/she is less likely to be influenced by the surrounding concerns. The smaller the CF_k is, the standard expert is more likely to amplify the concerns of others about him/her.

The adjusted empathetic centrality is:

$$EC_k^{*} = \rho w_{kk} + (1-\rho)\sum_{i\in A(k)} w_{ik} \tag{9}$$

The IOWA operator $\phi_\eta^{EC^*}$ with empathetic centrality as the induced value, i.e., the *EC*-OIWA* operator gathers individual decision making information to form group decision linguistic information.

Firstly, by referring to the practices of Yager R [51] and Yao Shengbao [27] , the weights when gathering individual decision making information are calculated with $\eta_{\sigma(h)}=\left(\eta_{\sigma(1)},\eta_{\sigma(2)},\dots,\eta_{\sigma(m)}\right)^T$, $\eta_{\sigma(h)}\in(0,1)$, $\sum_{h=1}^{m}\eta_{\sigma(h)}=1$, and the $\eta_{\sigma(h)}$ represents the weights of the attribute values given by the experts corresponding to the *hth* largest EC^* value.

$$\eta^{EC}_{\sigma(h)} = Q\left(\frac{h}{m}\right)-Q\left(\frac{h-1}{m}\right),\ h=1,2,\dots,m \tag{10}$$

$$Q(r)=r^{\delta} \tag{11}$$

δ is called the empathetic attitude parameter, which assigns different weights to the *EC*-OIWA* operator. When $\delta = 1$, $\eta^{EC^*}=\left(\frac{1}{m},\frac{1}{m},\dots,\frac{1}{m}\right)$; when $\delta = +\infty$, $\eta^{EC^*} = (0, 0, \dots, 1)$; when $\delta\in(0,1)$, $\eta^{EC^*}_{\sigma(m)}\le\dots\le\eta^{EC^*}_{\sigma(2)}\le\eta^{EC^*}_{\sigma(1)}$; and when $\delta\in(1,+\infty)$, $\eta^{EC^*}_{\sigma(1)}\le\eta^{EC^*}_{\sigma(2)}\le\dots\le\eta^{EC^*}_{\sigma(m)}$.

Group information is gathered as:

$$\Delta^{-1}\left(s^c_{u_{pq}},\alpha^c_{u_{pq}}\right)=\phi_\eta^{EC^*}\left(\left\langle EC_1^*,\Delta^{-1}\left(S^1_{u_{pq}},\alpha^1_{u_{pq}}\right)\right\rangle,\left\langle EC^*_2,\Delta^{-1}\left(S^2_{u_{pq}},\alpha^2_{u_{pq}}\right)\right\rangle,\dots,\left\langle EC^*_m,\Delta^{-1}\left(S^m_{u_{pq}},\alpha^m_{u_{pq}}\right)\right\rangle\right)=\sum_{h=1}^{m}\eta^{EC^*}_{\sigma(h)}\Delta^{-1}\left(S^{\sigma(h)}_{u_{pq}},\alpha^{\sigma(h)}_{u_{pq}}\right) \tag{12}$$

$$\Delta^{-1}\left(s^{\dot{c}}_{v_{pq}},\alpha^{\dot{c}}_{v_{pq}}\right)=\phi_\eta^{EC^*}\left(\left\langle EC_1^*,\Delta^{-1}\left(S^{\dot{1}}_{v_{pq}},\alpha^{\dot{1}}_{v_{pq}}\right)\right\rangle,\left\langle EC^*_2,\Delta^{-1}\left(S^{\dot{2}}_{v_{pq}},\alpha^{\dot{2}}_{v_{pq}}\right)\right\rangle,\dots,\left\langle EC^*_m,\Delta^{-1}\left(S^{\dot{m}}_{v_{pq}},\alpha^{\dot{m}}_{v_{pq}}\right)\right\rangle\right)=\sum_{h=1}^{m}\eta^{EC^*}_{\sigma(h)}\Delta^{-1}\left(S^{\dot{\sigma}(h)}_{v_{pq}},\alpha^{\dot{\sigma}(h)}_{v_{pq}}\right) \tag{13}$$

The group decision making matrix is:

$$M_c=\left(\left(s^c_{u_{pq}},\alpha^c_{u_{pq}}\right),\left(s^{\dot{c}}_{v_{pq}},\alpha^{\dot{c}}_{v_{pq}}\right)\right)_{p\times q}=\left(\Delta^{-1}\left(s^c_{u_{pq}},\alpha^c_{u_{pq}}\right),\Delta^{-1}\left(s^{\dot{c}}_{v_{pq}},\alpha^{\dot{c}}_{v_{pq}}\right)\right)_{p\times q} \tag{14}$$

Where $EC_{\sigma(h-1)}\le EC_{\sigma(h)}$, $0\le\eta^{EC}_{\sigma(h-1)}\le\eta^{EC}_{\sigma(h)}$, $\sum_{h=1}^{m}\eta^{EC}_{\sigma(h)}=1$.

Consensus Level Measurement

In this section, the distance between individual decision making-making and group decision making is used to measure the level of group consensus. The linguistic expression information of individual decision making-making is $S^k=\left(\left(S^k_{u_{pq}},\alpha^k_{u_{pq}}\right),\left(S^{\dot{k}}_{v_{pq}},\alpha^{\dot{k}}_{v_{pq}}\right)\right)$, and the linguistic expression information of group decision making gathered in the previous section is $S^c=\left(\left(s^c_{u_{pq}},\alpha^c_{u_{pq}}\right),\left(s^{\dot{c}}_{v_{pq}},\alpha^{\dot{c}}_{v_{pq}}\right)\right)$, and the distance between them is $d(S^c, S^k)$ [52].

$$d\left(S^c,S^k\right)=\left(\varepsilon\left|x_c-x_k\right|^{\lambda}+(1-\varepsilon)\left|y_c-y_k\right|^{\lambda}\right)^{\frac{1}{\lambda}} \tag{15}$$

Where $x_c=\frac{u^c_{pq}+\alpha^c_{pq}}{g}$, $x_k=\frac{u^k_{pq}+\alpha^k_{pq}}{g}$, $y_c=\frac{v^{\dot{c}}_{pq}+\alpha^{\dot{c}}_{pq}}{h}$, $y_k=\frac{u^k_{pq}+\alpha^k_{pq}}{g}$. When $\lambda = 1$, $d(S^c, S^k)$ is the Hamming distance, and when $\lambda = 2$, $d(S^c, S^k)$ is the Euclidean distance.

The individual consensus is:

$$CI_k = 1-d\left(S^c,S^k\right) \tag{16}$$

The expert weight is:

$$\eta_k=\frac{EC_k^*}{m} \tag{17}$$

The group consensus is:

$$GCI=\sum_{k=1}^{m}\eta_k CI_k \tag{18}$$

In the actual decision-making process, the threshold value τ of group consensus level is usually set in advance. If $GCI \geq \tau$, then it indicates that group consensus is reached; if $GCI \leq \tau$, then it indicates that there are differences in group opinions, and the feedback mechanism needs to be activated to improve the group consensus level by adjusting the decision results of group members.

Feedback Mechanism

In the feedback mechanism, firstly, it is necessary to identify the members who need to adjust their decisions, and the identification rule is the member with the smallest individual consensus, i.e., the member with the farthest distance from the result of the group decision making.

$$e_k^{adj} = \max\left\{ d\left(S^c, S^k\right)\right\} \tag{19}$$

Since group members tend to accept the assumption that they have preferences to whom they have empathetic relations, this section establishes adjustment rules by using empathetic relations as an important source of information for the adjustment of suggestions. The adjusted decision matrix M_k^{l+1} of e_k^{adj} is:

$$M_k^{l+1} = \theta M_k^l + \frac{(1-\theta)}{2}\left(M_{kj} + M_c\right) \tag{20}$$

where M_k^l is the decision matrix of e_k^{adj}, M_{kj} is the set of decision matrices of empathetic subjects, M_c is the group decision making matrix, and θ is the feedback adjustment coefficient. θ represents the weight of own decision information of e_k^{adj}, and the confidence index ρ_k ($k = 1, 2, ..., m$) above represents the expert's reliability of his own decision information, which can be expressed by $\rho_k(\theta = \rho_k)$.

Solution Ordering

The group decision making matrix for reaching agreement is:

$$M_c^* = \left(\left(s_{pq}, \alpha_{pq}\right), \left(\dot{s}_{pq}, \dot{\alpha}_{pq}\right)\right)_{p\times q} \tag{21}$$

The decision information for each solution is gathered by using a 2-dimension 2-tuple linguistic information weighted averaging operator, and the evaluation value of the solution X_p is:

$$2DLWAA\left(S_{p1}, S_{p1}, \dots, S_{pr}\right) = \Delta\left(\sum_{q=1}^{r} \omega_{pq}\Delta^{-1}\left(S_{pq}, \alpha_{pq}\right), \sum_{q=1}^{r} \omega_{pq}\Delta^{-1}\left(\dot{S}_{pq}, \dot{\alpha}_{pq}\right)\right) \tag{22}$$

Calculate its expected value and rank the solutions, and the expected value is [53]:

$$E\left(S_p\right) = \frac{\Delta^{-1}\left(S_{pq}, \alpha_{pq}\right)}{g} \times \frac{\Delta^{-1}\left(\dot{S}_{pq}, \dot{\alpha}_{pq}\right)}{h} \tag{23}$$

Solution ordering can be performed based on the magnitude of the expected value.

The process of a consensus model for group decision making of 2-dimension 2-tuple linguistic information based on empathetic relations is as follows.

Input: the experts' decision matrix $M_k = \left(m_{pq}^k\right)_{n\times r} = \left(\left(s_{u_{pq}}^{\dot{k}}, \alpha_{u_{pq}}^{\dot{k}}\right), \left(s_{v_{pq}}^{\dot{k}}, \alpha_{v_{pq}}^{\dot{k}}\right)\right)_{n\times r}$, experts' empathy adjacency matrix $W = (w_{ij})_{m\times m}$, threshold τ for group consensus level, empathetic attitude parameter δ, distance adjustment parameter ε, feedback adjustment coefficient θ.

Output: the optimal solution x_{opi}

Step 1. Let $l = 0$, construct the confidence index according to equation (8), calculate the adjusted empathetic centrality according to equation (9), and calculate the group decision making matrix according to Equation (10)-Equation (14).

Step 2. Calculate the distance $d(S^c, S^k)$ between the individual decision making matrix and the group decision making matrix according to Equation (15).

Step 3. Calculate the group consensus level $GCI^{(1)}$, 1 according to Equation (16)-Equation (18). If $GCI^{(1)} \geq \tau$, go to step 7; if $GCI^{(1)} \leq \tau$, go to step 4.

Step 4. Identify the individual e_k^{adj} to be adjusted according to Equation (19).

Step 5. Adjust the decision information of the individual e_k^{adj} according to Equation (20). Let $l = l + 1$, and then go to step 1.

Step 6. Calculate the expected value $E(S_p)$ of each solution in the group decision matrix M_c^l according to Equation. (21)-Equation. (23) and determine the optimal solution.

A Consensus Model for Group Decision Making of Environmental Governance Capacity Based on Empathetic Relations

A government agency invites five experts e_1, e_2, e_3, e_4, and e_5 in the field of environmental governance to evaluate the environmental governance capacity of three cities x_1, x_2, x_3. After discussion, the experts will evaluate them from four aspects: regulations and policies c_1, corporate responsibility c_2, risk prevention and control c_3, and governance costs c_4. The linguistic evaluation set for attribute values is $S = \{s_0 =$ *highly poor*, $s_1 =$ *very poor*, $s_2 =$ *poor*, $s_3 =$ *medium*, $s_4 =$ *good*, $s_5 =$ *very good*, $s_6 =$ *highly good*$\}$, and the linguistic evaluation set for certainty is $\dot{S} = \left\{\dot{s}_0 = unsure, \dot{s}_1 = little\ sure, \dot{s}_2 = sure, \dot{s}_3 = very\ sure, \dot{s}_4 = highly\ sure\right\}$. The evaluation matrices given by 5 experts for different environmental governance situations are shown in Table 1.

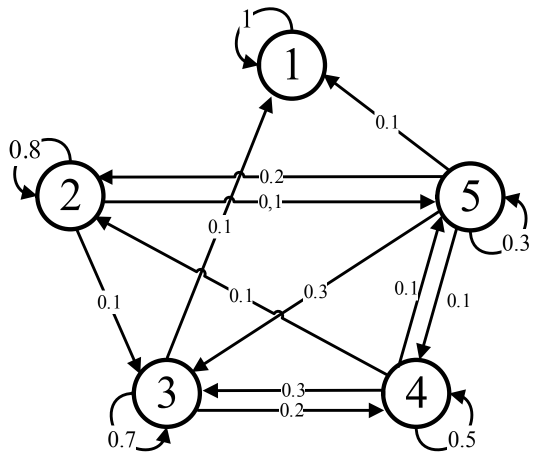

Fig. 2. Empathy network of the 5 experts.

Since the five experts were from the same field and knew each other, the corresponding empathy network is:

The empathy matrix $W = (w_{ij})_{m\times m}$ is:

$$W = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0.8 & 0.1 & 0 & 0.1 \\ 0.1 & 0 & 0.7 & 0.2 & 0 \\ 0 & 0.1 & 0.3 & 0.5 & 0.1 \\ 0.1 & 0.2 & 0.3 & 0.1 & 0.3 \end{pmatrix}$$

Step 1. Calculate the group decision making matrix according to Equation (8)-Equation (14).

Firstly, calculate and gather the induced value of the individual decision making matrix, i.e., the empathy centrality EC_k^* of each expert. Let the confidence coefficient $\gamma = 0.3$.

$$\begin{aligned} EC_k^* &= \rho w_{kk} + (1-\rho)\sum w_{ik} \\ &= CF_k^{0.3} w_{kk} + \left(1 - CF_k^{0.3}\right)\sum w_{ik} \end{aligned}$$

The empathetic centrality of each expert is $EC_1^* = 0.4568$, $EC_2^* = 0.4409$, $EC_3^* = 0.7$, $EC_4^* = 0.3482$, $EC_5^* = 0.2204$.

Then, calculate the weights $\eta_{\sigma(h)} = \left(\eta_{\sigma(1)}, \eta_{\sigma(2)}, \dots, \eta_{\sigma(m)}\right)^T$, $\eta_{\sigma(h)} \in (0,1)$, $\sum_{h=1}^{m} \eta_{\sigma(h)} = 1$ when gathering individual

Table 1. Evaluation matrix given by the experts.

		c_1	c_2	c_3	c_4
e_1	x_1	$((s_5,0.3),(s_4,0))$	$((s_6,-0.2),(s_4,-0.3))$	$((s_6,-0.5),(s_4,-0.1))$	$((s_6,-0.3),(s_4,-0.3))$
	x_2	$((s_6,0),(s_4,-0.1))$	$((s_6,0),(s_3,0))$	$((s_6,0),(s_4,-0.5))$	$((s_6,0),(s_4,-0.3))$
	x_3	$((s_5,0),(s_4,-0.2))$	$((s_3,0.3),(s_3,0.1))$	$((s_5,0.3),(s_4,-0.5))$	$((s_4,-0.5),(s_4,-0.2))$
e_2	x_1	$((s_5,0),(s_3,0))$	$((s_6,-0.2),(s_4,-0.5))$	$((s_6,0),(s_4,0))$	$((s_6,0),(s_2,0.5))$
	x_2	$((s_6,-0.5),(s_4,-0.3))$	$((s_6,-0.3),(s_2,0.4))$	$((s_6,0),(s_3,0))$	$((s_5,-0.5),(s_2,0.2))$
	x_3	$((s_6,0),(s_3,0))$	$((s_3,0),(s_3,0.2))$	$((s_5,0.5),(s_4,-0.3))$	$((s_2,-0.5),(s_2,0))$
e_3	x_1	$((s_4,0.3),(s_3,0))$	$((s_5,0.1),(s_4,0))$	$((s_2,0.5),(s_4,-0.4))$	$((s_6,-0.3),(s_3,-0.2))$
	x_2	$((s_6,-0.2),(s_2,0.2))$	$((s_5,0.2),(s_4,-0.2))$	$((s_6,-0.2),(s_3,0))$	$((s_3,0.4),(s_3,-0.1))$
	x_3	$((s_5,0),(s_3,-0.5))$	$((s_2,0.2),(s_2,0.3))$	$((s_5,-0.5),(s_1,0.3))$	$((s_2,0.2),(s_2,0))$
e_4	x_1	$((s_6,-0.5),(s_3,-0.4))$	$((s_6,-0.5),(s_4,-0.5))$	$((s_5,0),(s_4,-0.3))$	$((s_5,0),(s_3,0))$
	x_2	$((s_6,0),(s_3,-0.2))$	$((s_6,0),(s_3,-0.5))$	$((s_6,0),(s_4,-0.1))$	$((s_5,-0.4),(s_2,-0.3))$
	x_3	$((s_4,0),(s_2,0))$	$((s_2,0),(s_2,0))$	$((s_2,0),(s_2,-0.5))$	$((s_1,0),(s_1,-0.1))$
e_5	x_1	$((s_5,-0.2),(s_3,-0.1))$	$((s_6,-0.5),(s_3,0.2))$	$((s_5,0),(s_3,0))$	$((s_4,0),(s_2,0))$
	x_2	$((s_6,-0.2),(s_2,0))$	$((s_6,0),(s_2,-0.1))$	$((s_6,0),(s_3,-0.5))$	$((s_3,-0.5),(s_2,0.3))$
	x_3	$((s_2,0.3),(s_1,0))$	$((s_3,0),(s_2,-0.2))$	$((s_3,0),(s_2,0))$	$((s_4,0),(s_4,0))$

decision making information. Let the empathetic attitude parameter $\delta = 0.4$.

$$\eta^{EC}_{\sigma(h)} = Q\left(\frac{h}{m}\right) - Q\left(\frac{h\text{-}1}{m}\right) = \left(\frac{h}{m}\right)^{0.4} - \left(\frac{h\text{-}1}{m}\right)^{0.4}$$

The weights ordered by induced values are: $\eta^{EC}_{\sigma(1)}=0.5253$, $\eta^{EC}_{\sigma(2)}=0.1678$ $\eta^{EC}_{\sigma(3)}=0.1220$ $\eta^{EC}_{\sigma(4)}=0.0994$ $\eta^{EC}_{\sigma(5)}=0.0853$

and the corresponding weights in the process of gathering individual decision information are: $\eta^{EC}_{1}=0.1678$, $\eta^{EC}_{2}=0.1220$ $\eta^{EC}_{3}=0.5253$ $\eta^{EC}_{4}=0.0994$ $\eta^{EC}_{5}=0.0853$.

Calculate the group decision making matrix according to Equation (12) and Equation (13) to obtain the evaluation of the 2-dimension 2-tuple linguistic information of group decision making.

Step 2. Calculate the distance between each expert's decision making matrix and the group decision making matrix according to Equation (15).

This section defines $d(S^c, S^k)$ as the Hamming distance, $\lambda = 1$, $\varepsilon = 0.7$. $d(S^c, S^1) = 0.0572$, $d(S^c, S^2) = 0.0945$, $d(S^c, S^1) = 0.1391$, $d(S^c, S^1) = 0.2885$ and $d(S^c, S^1) = 0.3316$.

Step 3. Calculate the group consensus level $GCI^{(1)}$ according to Equation (16)-Equation (18).

Calculate the individual consensus level of experts according to Eq. (16): $CI_1 = 0.9428$, $CI_2 = 0.9055$, $CI_3 = 0.8609$, $CI_4 = 0.7115$, and $CI_5 = 0.6684$.

The expert weights are calculated according to equation (17): $\eta_1 = 0.2108$, $\eta_2 = 0.2035$, $\eta_3 = 0.3231$, $\eta_4 = 1607$, and $\eta_5 = 0.1017$.

The group consensus level is calculated according to Equation (18).

$$GCI^{(0)} = \sum_{k=1}^{m} \eta_k CI_k = 0.8436$$

Let the threshold value $\tau = 0.9$, obviously, $GCI^{(0)} \le \tau$ which indicates that the group consensus has not reached the preset level, and the feedback mechanism needs to be activated to improve the consensus level.

Step 4. Identify and adjust e_k^{adj} according to Equation (19) and Equation (20).

The identification rule is the member with the smallest individual consensus, i.e., the member with the farthest distance from the group decision making outcome, i.e e_5.

Adjust e_5 according to Equation (20). Where, M_k^l is the decision making matrix of the previous round e_5, M_c is the group decision gathered in step 1, M_{kj} is the set of decision information expressed by the empathy object of e_5, and the empathy relationship comes from $W = (w_{ij})_{m \times m}$. θ is the feedback adjustment coefficient, e_5 representing the proportion of their own decision information, which can be expressed with confidence index ρ_k (k = 1, 2, ..., m). Obtain the decision making matrix $M_5^{(l)}$ after the adjustment of e_5.

Step 5. Let $l = l + 1$, go to step 1.

After 7 iterations, $GCI^{(7)} = 0.9001 > \tau$, and the group reached consensus. The group decision making matrix at this time is:

Step 6. Calculate the expected value of each plan in the group decision making matrix according to Equation (21)-Equation (23)

After discussion by 5 experts, the weights of the four attributes, laws and policies, corporate responsibility, risk prevention and control, and governance costs are as follows. Use the two-dimensional 2-dimension 2-tuple linguistic information weighted averaging operator to gather the decision information of each plan, and the evaluation value of the plan is:

According to Equation (23), $E_1(S) = 0.8338$, $E_2(S) = 0.8165$, $E_3(S) = 0.5921$ and the order of the solutions is: $x_1 \succ x_2 \succ x_3$. That is, city 1 has the strongest environmental governance, city 2 has the second strongest environmental governance capability, and city 3 has the worst environmental governance capability.

Discussion

The evaluation of environmental governance capacity is a multi-attribute decision-making problem led by the government and participated by all levels of society. There are few evaluation models involving environmental governance capacity in the current research, mainly due to the following points. Firstly, in the actual decision-making process, it is difficult for evaluation experts to have a comprehensive understanding of environmental governance capacity because of its complexity and versatility. Secondly, the invited evaluation experts are different in knowledge structure, professional background and so

Table 2. Group decision making matrix ($l = 0$).

		c_1	c_2	c_3	c_4
e_1	x_1	$((s_5,0.2),(s_4,-0.5))$	$((s_6,-0.3),(s_4,-0.2))$	$((s_5,0.4),(s_4,-0.3))$	$((s_6,-0.4),(s_3,0.2))$
	x_2	$((s_6,-0.1),(s_3,0.4))$	$((s_6,\text{-}0.1),(s_3,0.1))$	$((s_6,0),(s_4,-0.5))$	$((s_5,0),(s_3,0))$
	x_3	$((s_5,0.2),(s_3,0.1))$	$((s_3,0),(s_3,\text{-}0.2))$	$((s_5,\text{-}0.2),(s_3,0))$	$((s_3,0.2),(s_3,0))$

Table 3. The adjusted decision matrix $M_5^{(l)}$ (l = 1).

		c_1	c_2	c_3	c_4
$e_5^{(1)}$	x_1	$((s_5,0),(s_3,0.2))$	$((s_6,-0.5),(s_4,-0.4))$	$((s_5,-0.1),(s_3,0.3))$	$((s_5,0.2),(s_3,-0.2))$
	x_2	$((s_6,-0.2),(s_3,-0.1))$	$((s_6,-0.2),(s_3,-0.5))$	$((s_6,0),(s_3,0.1))$	$((s_4,0),(s_3,-0.3))$
	x_3	$((s_4,0.4),(s_2,0.4))$	$((s_3,-0.2),(s_3,-0.5))$	$((s_4,0.2),(s_3,-0.5))$	$((s_3,0),(s_3,-0.3))$

Table 4. Group decision making matrix $M_c^{(7)}$ (l = 7).

		c_1	c_2	c_3	c_4
$M_c^{(7)}$	x_1	$((s_5,0.1),(s_4,-0.4))$	$((s_6,-0.3),(s_4,-0.1))$	$((s_5,0.3),(s_4,-0.1))$	$((s_6,-0.1),(s_3,0.3))$
	x_2	$((s_6,-0.1),(s_4,-0.5))$	$((s_6,-0.2),(s_3,0.4))$	$((s_6,0),(s_3,0.3))$	$((s_5,0.2),(s_3,0.3))$
	x_3	$((s_6,-0.4),(s_3,0.4))$	$((s_3,0),(s_3,0))$	$((s_5,0.2),(s_3,0.2))$	$((s_3,-0.1),(s_3,0.1))$

on. In addition, the actual decision-making process is an open environment, so the evaluation experts are not completely independent. There may be a certain social relationship between them, and it is very difficult for the evaluation experts to make a completely rational judgment. In short, such decision making problems are more or less affected by a series of factors such as feelings and social relations. The decision-making information given by evaluation experts in the form of scoring and ranking is likely to be processed and does not necessarily reflect their most real ideas.

The contribution of this paper is that the evaluation of environmental governance capacity is regarded as a social network group decision making problem. Firstly, language information, that is, 2-dimension 2-tuple linguistic information, is used to express the opinions of evaluation experts, which can better reflect the most real, direct and accurate ideas of evaluation experts. Second, this paper uses empathetic relations to describe the social relationship between experts. Empathy reflects the individual's understanding of others' emotions and attention to others' welfare. This description can reflect the phenomena of "influential people" or "Irrational influence on experts" in the decision-making process. Thirdly, this paper introduces the concept of confidence index to improve the rationality and accuracy of decision-making results. Different impressions are given by confident evaluation experts and non confident experts when expressing views. This improvement makes the decision-making results more in line with the actual situation.

In terms of theoretical significance, the model proposed in this paper is an extension of the social network group decision-making model, it discusses the consensus reaching process considering the confidence level of decision makers in the language environment. In terms of application value, there are few models involved in the evaluation of environmental governance capacity in the current research. The method proposed in this article considers the characteristics of environmental governance capability evaluation issues and similar government-led evaluation issues, such as diverse personnel structure, complex social network, multiple evaluation attributes, etc. The model can reflect the real opinions of evaluation experts, and the solution process is more convenient. The example analysis proves the effectiveness and scientificity of the method. Therefore, the evaluation model proposed in this paper is easy to implement and popularize, and it provides a new way for the evaluation of environmental governance capacity, so that it has certain practical significance.

Table 5. Evaluation by Group.

	c_1
x_1	$((s_5,0.4),(s_4,-0.3))$
x_2	$((s_6,-0.2),(s_3,0.4))$
x_3	$((s_4,0.4),(s_3,0.2))$

Conclusion

The assessment of environmental governance capacity involves experts from different backgrounds, who have different expression habits, social relations and influence, which have great influence on consensus and decision-making. It is a challenge for us to use the information that can express experts' opinions truly and accurately, to integrate the information index of experts' psychological changes, and to determine the social network that can reflect the relationship between experts.

Based on this, this paper proposes an environmental governance capability evaluation model, which can solve the above problems, this is a consensus model for group decision making of 2-dimension 2-tuple linguistic information based on empathetic relations. The steps to reach consensus and make decisions are as follows: (1) The model uses 2-dimension 2-tuple linguistic information to express decision making information, uses empathetic relations to build social networks, and uses empathy centrality to describe the influence of experts. (2) On this basis, The confidence index is first constructed by using linguistic information, and the confidence index is used to adjust the empathetic centrality so that the empathetic centrality is incorporated into the expert psychological change factors. (3) Then, the expert decision information is gathered by using empathetic centrality as the induced value. The group consensus level is calculated by measuring the distance between individuals and groups, and a consensus adjustment method is established by using the confidence index. (4) Then the evaluation results are obtained by using a 2-dimension 2-tuple linguistic information weighted averaging operator to process the group decision information that reaches consensus. (5) Finally, the feasibility and effectiveness of the method is analyzed by using an example of the evaluation of environmental governance capacity. The results of case show that the model proposed in this paper can solve the problem of environmental governance capacity evaluation.

The evaluation of environmental governance capacity in the real world is much more complex than what we discussed. In the following research, we will improve in the following aspects: (1) the clustering method can be used to extend the research results of this paper to large group decision-making with more than 20 people, so as to enrich the application scenarios of environmental governance capacity evaluation. (2) In the future, the parameters in the model will be studied to explore the selection of optimal parameters. (3) We will conduct further study into the rational establishment of social relations.

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Conflict of Interest

The authors declare no conflict of interest.

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