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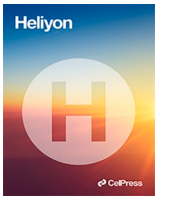

Structural analysis of global mineral governance system from the perspective of country

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ABSTRACT

The uneven spatial distribution of mineral resources necessitates the construction of mature global mineral governance system to ensure rational allocation of mineral resources. To this end, it is essential to analyze the structure of the global mineral governance system to provide a theoretical basis for the construction. The governance actor is the crucial element in driving the governance process, and country serves as the most central actor. Therefore, clarifying the roles and statuses of different countries in the governance system will be helpful to analyze the structure of the governance system. In the context of advancing globalization, a complex cooperative relationship has been presented between countries based on international organizations. Thus, we establish a national cooperation network based on the principle of the co-existence of countries in international organizations, to quantify these relationships between countries and identify the role and status of different countries, as well as the country communities in the cooperation network, by combining the characteristics of the countries in the network with the actual performance in the organizations. The research findings are as follow: (1) The UK, Germany, France, Sweden, and Canada play pivotal roles in promoting international cooperation as well as leading governance in the governance system. (2) Emerging economies are more actively engaged in these organizations and can promote international cooperation, but lack the capacity to assume leadership roles in governance. (3) The U.S. and China have a stronger ability to lead than to cooperate in the governance system. (4) Most African and South American countries, as well as some European nations, are marginalized in the governance system. (5) Countries with the same needs and similar economic and political conditions belong to the same community: The European countries and the U.S., consumer with a high level of economic and political development but low mineral resource endowment are in the first community. Canada, Australia, and certain African and South American countries, producers with high mineral resource endowments are in the second community. Most African and South American countries with lower levels of economic and political development are in the third group.

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1. Introduction

As the cornerstone of industrial development, mineral resources are critical to national economic development, and the supply security is directly related to national security. Owing to geological laws, the global spatial distribution of minerals is naturally uneven, therefore, it is impossible for any country to fully realize self-sufficiency in mineral resources. Consequently, allocating the required mineral resources globally is an unavoidable and inevitable choice for all countries [1]. As a result, constructing a reasonable and rule-based global governance system for mineral resources, which can guarantee stable global mineral trade flows and resource security, is imperative. Therefore, it is vital to analyze the current global mineral governance system to provide a theoretical basis for the construction of a mature system. In the existing studies on global mineral governance, domestic and foreign scholars have summarized the public problems faced globally [2], and analyzed the current situation, problems, and mechanism construction of global governance in specific areas, such as Antarctic mineral resources, deep-sea mineral resources, green mining standards, intergenerational distribution of mineral resources, and supply security of mineral resources to support the clean energy transition [2–6]. Based on these analyses, they have put forward policy recommendations to improve the existing global mineral governance system [7,8]. Although the research content is relatively comprehensive, a unified research paradigm has not yet been formed to analyze the structure of the global mineral governance system. In 1995, the Commission on Global Governance issued the report *Our Global Neighborhood*, which firstly put forward the five elements of global governance: value, actor, mechanism, issue and effect [9]. Subsequently, the report *Mineral Resource Governance in the* 21st *Century* issued by the United Nations Environmental Programme in 2020 has pointed out that the actor is the key factor to drive the process of global governance [8], which provides an entry point for us to analyze the structure of the global governance system.

International organizations are the most important governance actor in the current governance system [8], including non-governmental organizations (NGOs) composed of industry associations, businesses, and civil society groups, as well as intergovernmental organizations (IGOs) comprising states. International organizations have also been researched by scholars, including the typology of organizations, the complex relationships that exist between organizations based on the countries, and the qualitative analysis of the functions and roles of various types of organizations [10–13]. However, international organizations are tools and instruments for countries to participate in global governance, and behind these organizations, it is the countries that dictate the logic of action as well as the strategic direction of organizations [14,15]. Different countries have different role and status in the existing governance system due to differences in mineral resource endowment, degree of economic development and political stability. Therefore, research on the role and position of different countries in the governance system will help to more clearly understand the structure of the global mineral governance system.

In the research on the field of global mineral governance, the studies targeting countries often focus on the influencing factors of countries' participation in global governance [16,17]. However, with the advancement of globalization, a complex cooperative relationship has been presented between countries based on international organizations, and it is obvious that solely the analysis of influencing factors of countries' participation cannot completely dissect the structure of the governance system. Therefore, it is necessary to visualize the complex cooperation relationship between countries, which is the method to identify the role and status of countries in the governance system and to analyze the structure of the system.

The existing global mineral governance system is very complex, involving 52 international organizations and 114 countries, the details are shown in Table 1 of the Appendix. The cooperative relationship between countries based on international organizations has gradually formed a networking trend with the advancement of globalization, and it will be difficult to evaluate the structure of the entire complex system, analyze the position of countries in the governance system comprehensively and identify important national community in the governance system if only a qualitative analysis is conducted on the situation of a typical country. Thus, it is necessary to introduce an effective analytical tool. Complex network is a structural paradigm reflecting the connection between entities, which treats entities in complex systems as nodes and the relationship between entities into connecting lines, and by quantifying the closeness of the connecting lines, it provides us with a new way to research the complexity of the interactions between the countries as well as to identify important countries. The method has been applied to social networks in several fields, for example, researchers have constructed networks based on the principle of countries appearing simultaneously in the same news to identify key countries involved in political events [18–20], or analyzed key countries dominating global trade based on the commodity trade relations between countries [21–23]. It can be seen that the complex network approach can effectively analyze the complex connections and internal mechanisms between social entities driven by a certain factor. However, the identification of country status in the global governance system has not yet been researched by using the complex network approach. Therefore, based on the methodology's principle and applicability, we construct a national cooperation network relying on complex partnerships between countries. This enables us to identify the role and status of different countries in the governance system, as well as the communities formed by countries with the same characteristics, to more deeply analyze the structure of the governance system. Through the above research, it not only enriches the application field of complex network model, but also constructs a set of clear and logical analytical framework of the structure of global governance system. At the same time, we can understand the role and status of countries at different stages of economic development and different resource endowments in the governance system by portraying the cooperative relationship between countries. This approach not only provides a theoretical basis for how countries can participate in the global governance, but also lays a theoretical foundation for improving the governance efficiency of international organizations and realizing the sustainable development of the mineral resources industry.

The paper is structured as follows: The second section describes the data and methodology of the study, including: (1) The sources of information on international organizations for minerals and the countries included in each organization; and (2) The evaluation method for identifying the role and status of countries in the cooperation network, as well as the modeling of the complex network

involved in the methodology and the corresponding evaluation indicators and their meanings. The third section presents the results of the evaluation, identifying the role and status of countries in the governance system as well as the national communities derived through the cooperation network, and also discusses the evaluation result combining with the reality of mining market. The fourth section summarizes the conclusions of the research.

2. Data and method

2.1. Data

In this paper, mining-related international organizations are categorized into direct and indirect governance organizations. The direct are defined as those that aim to achieve the effective allocation of global mineral resources and the sustainable development of the global mining industry by resolving the economic, social and environmental problems of the mining industry, such as supply, investment and trade, price stabilization, responsible mining, and the development of polar resources, that exist in the process of the development of the mining industry. This category excludes academic organizations established to address theoretical research and technical issues such as mineral resource extraction, smelting, processing and manufacturing, as well as energy international organizations. The indirect are defined as comprehensive international organizations including, but not limited to the field of mineral resources, such as the WTO, World Bank, and G20. Since these organizations are involved in areas other than mineral resources and often include a diverse set of member countries, the construction of the complex network applies only direct organizations for ease of targeting the analysis, while in the discussion of the findings we will provide a comprehensive account in conjunction with the participation of indirect governance organizations.

Information on international organizations is sourced from the *Yearbook of International Organizations*, edited and published by the Union of International Associations (UIA), all organizations were established prior to 2022, and the specific contents are listed in Appendix. The countries included are taken from the official websites of the organizations, the International governmental organizations (IGOs) can count countries' information directly, while non-country participants in the NGOs, such as companies and associations, are counted according to the country to which they belong, shown as Fig. 1. A total of 40 international organizations and 114 countries have been analyzed in this paper. It should be emphasized that the countries referred to in this paper do not specifically refer to Taiwan, China and Hong Kong, China. The data were collected over a period of three months, and the research work on the data included data compilation, statistical analysis, and the generation of matrices required for constructing the complex network models.

2.2. Method

As mentioned above, we aim to construct a complex network model to facilitate the identification of the role and status of countries in the governance system via the evaluation indicators in the network and the actual performance of countries in international organizations. Subsequently, based on the complex network model and the cooperation between countries, we will identify the important national groups in the governance system.

2.2.1. Evaluation of role and status of countries in the governance system

In this paper, two dimensions are considered to identify the role and status of countries, including the willingness of the country to engage in governance, as well as its capacity to do so, as depicted in Fig. 2. Willingness refers specifically to the country's motivation to participate in organizations and its capacity for cooperation, which is evaluated based on important nodes in the complex network. Another dimension is the country's ability to dominate international organizations, measured by the frequency with which the country has served on the board of directors.

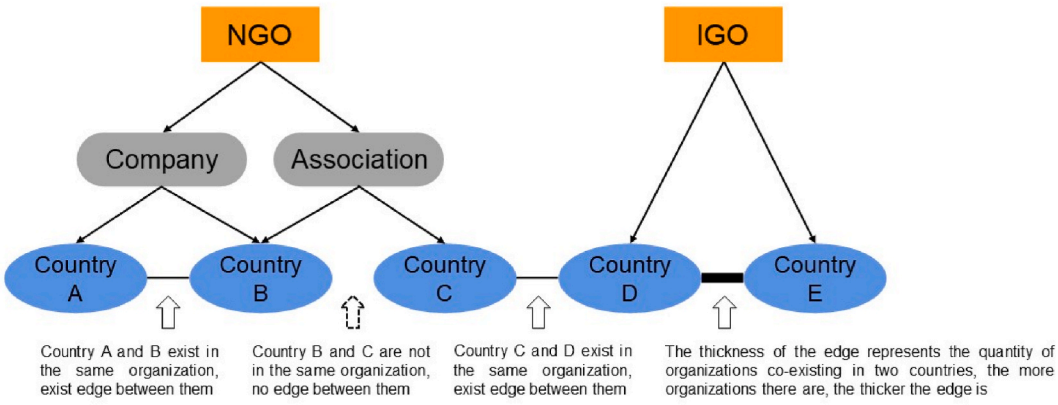

Fig. 1. Description of data applications and network building logic.

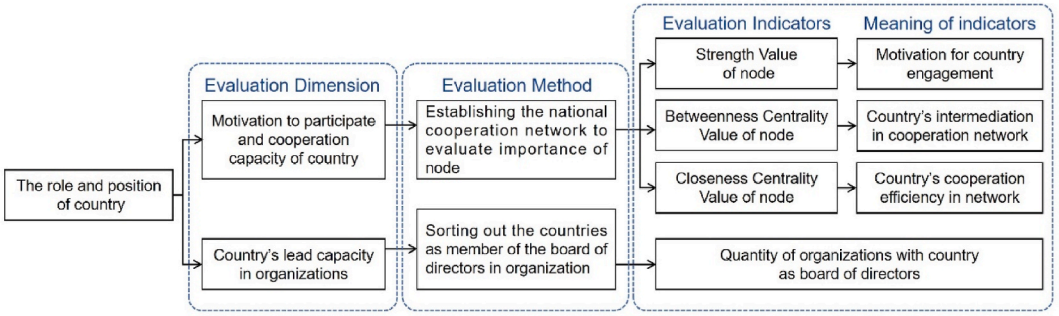

Fig. 2. Logical framework diagram for evaluating role and status of the country.

2.2.1.1. Construction of complex network. Taking countries as nodes, the cooperation relationship between countries is the connecting edges, if two countries co-occur with the same organization, then there is a connecting edge between them, the weight of the edge is the quantities of international organizations co-occurring in the two countries, and this is used as the principle to establish the network G = (V, W). Where $V_n = (V_i: i = 1, 2, 3 \ldots n)$ is the node in the network, corresponding to countries participating in international organizations, $W = (w_{ij}: i, j \in V_n)$ is the weight of the connected edge between two nodes, if two countries co-exist in the same international organization, then w_{ij} is not zero, and the value of w_{ij} is the quantity of international organization that two countries co-exist in. The logical schematic of complex network building is shown in Fig. 1. In the process of constructing the network, considering that the cooperation network is different from the trade network, which does not exist the material flow and flow direction, and also different from the citation network, which involve citation relationships. Although there are some international organizations in which the countries that have joined to invite others, due to the difficulty of data collection, the long period of time between now and then, which makes it unlikely to determine the order in which each country joined and whether it was invited or not. More importantly, our analysis is centered on analyzing the current governance patterns that emerge from inter-country cooperation, therefore, the network is constructed as an undirected network.

2.2.1.2. Indicators for evaluating the importance of nodes. In the existing research on complex networks, degree, strength, betweenness centrality, and closeness centrality are the key indicators for evaluating important nodes in the network. Degree is the quantity of other nodes that a node is connected to, the higher the value, the larger the neighbor size of the node, and the higher its importance becomes in the networks. For example, literature citation networks [24], trade networks [25], and aviation networks [26] have utilized to identify important countries in the network by using k-shell decomposition or deliberately attacking the networks in the order of the degree value from the largest to the smallest. However, as the research continues, the degree has some limitations in evaluating. If the weights are assigned to the edges, the weight value represents the closeness of the connection between the nodes, and only considering the degree value of the nodes will ignore the influence of the attributes of the edges on the nodes. To address this, the concept of 'strength' is introduced, and the strength value is the sum of the weight values on each edge of the node, which represents the node's ability to connect with the other nodes in the network [27], and higher strength values indicate more robust connectivity. Some scholars use material flow, traffic flow and other factors to respectively assign weights to edges in trade [28] and transportation network [29] to judge the important nodes with stronger connectivity in the network and optimize the network based on the changes in weights over the years. In addition, the fact that it is not enough to consider only the degree or strength of a node, which would ignore the possibility that nodes with small degree or strength may be important bridges connecting different regions of the network [30], so the reflection of the connectivity paths in terms of the importance of the nodes should also be considered - betweenness centrality and closeness centrality [31]. Betweenness centrality is a measure of the node's ability to act as a mediator; the higher the value, the much shortest paths through this node, and the stronger the node's influence in network propagation. Closeness centrality quantifies the distance from a node to all other nodes in the network. A lower value indicates greater remoteness, positioning the node more peripherally within the network structure [32]. In geopolitical cooperation networks with countries as nodes, betweenness centrality and closeness centrality are commonly used as indicators for evaluating a country's status, and some scholars believe that these two indicators can be translated into the country's influence in the network and the efficiency of its cooperation with other countries, which is, to some extent, a manifestation of whether or not the country has political capacity [33,34].

In light of the above literature, we opt for strength, betweenness centrality, and closeness centrality as indicators for evaluating important countries in the network. Additionally, degree is not applicable in this network due to the fact that we sets that if a country co-occurs with other countries in the same organization, there exists a connecting edge between them, but assuming that the country joins only one international organization, when the organization contains a very large number of countries, all of them constitute a connecting edge between this country and those countries, and this country's degree has a very high value, but it obviously does not indicate that this country is important in the cooperation network. Conversely, a high strength value more reliably indicates a country's active participation across multiple organizations, making it a more suitable metric for our analysis. The equation for calculating and standardizing indicators are shown below.

(1) Strength value is shown as Equations (1) and (2):

$$S_i = \sum_{j=1}^{g} w_{ij} \tag{1}$$

$$S_i^{'} = \frac{S_i - \min(S_i)}{\max(S_i) - \min(S_i)} \tag{2}$$

where S_i represents the strength value of node i; w_{ij} represents the weights of connected edges between node i and all nodes, g is the quantity of nodes in the networks. S'_i is the standardization of S_i, this can be standardized to the range from 0 to 1, which helps our analysis later on, max (S_i) and min (S_i) are the biggest and smallest of all strength values, respectively.

(2) Betweenness Centrality value is shown as Equations (3) and (4):

$$C_{B(n_i)} = \frac{\sum_{j<k} g_{jk}(n_i)}{g_{jk}} \tag{3}$$

$$C_B^{'}(n_i) = \frac{C_B(n_i) - \min\left(C_B(n_i))n_i\right))C_B}{\max(C_B(n_i)) - \min\left(C_B(n_i))n_i\right))C_B} \tag{4}$$

where C_B (n_i) is the betweenness centrality of node i, g is the total number of nodes in the network, g_{jk} is the quantity of connecting edges between nodes j and k, and g_{jk} (n_i) is the quantity of connecting edges that pass through i in the connecting edges of j and k. C'_B (n_i) is the standardization of $C_B(n_i)$, where max ($C_B(n_i)$) and min ($C_B(n_i)$) are the biggest and smallest of all betweenness centrality values, respectively.

(3) Closeness Centrality value is shown as Equation (5):

$$C_C(n_i) = \left[\sum_{i \neq j}^{g} d(n_i, n_j)\right]^{-1} \tag{5}$$

where C_C (n_i) is the closeness centrality of node i, g is the quantity of nodes in the network, and d (n_i, n_j) is the connection distance between nodes i and j. Since the values of the closeness centrality are in [0, 1], no need for standardization.

2.2.1.3. Evaluation the importance of node in the network. Based on the above indicators, we established a model for evaluating the importance of node in the cooperation network, as shown in Equation (6). The logic of evaluation is that a country is considered to be of high importance in the network when it demonstrates a high participation motivation for cooperation among countries, as well as when the country has a high level of intermediation, influence and efficiency in cooperation with other countries.

$$I_C = S_i^{'} \times C_B^{'}(n_i) \times C_C(n_i) \tag{6}$$

2.2.1.4. Statistics on the quantity of organizations with countries as board members. Motivation to participate in organizations and capacity for cooperation of the country don't fully represent the countries' role and status within the governance system. Another critical aspect to consider is whether a country can assume a dominant role within the organizations it participates in. The board of directors is the implementer of the core business of formulating the relevant rules and advancing the objectives of governance [16,35], and the ability of a country to become a member of the board of directors can be used as an indicator of its dominant status within international organizations. Based on the information about the board of directors of each international organization, the countries to which the board members belong are counted using statistical methods, which are visualized by drawing bar charts.

2.2.2. Identification of national groups

In the global governance system, countries differ in terms of economic prowess, resource availability, international standing, and collaborative capabilities, so there may be association structures in the network as a result of the different degrees of closeness of connections between nodes, that is, according to the strength of the nodes and the difference in the weight of the edges, the nodes will be classified into the corresponding associations, the connections between nodes within a club are relatively strong. The association partitioning can be realized automatically in the Gephi software used for complex network modeling, which is calculated as shown in Equations (7) and (8). The quality of association partitioning is examined using the modularity algorithm developed by Blondel [36].

$$Q = \frac{1}{2m}\sum_{i,j}\left[w_{ij} - \frac{s_i s_j}{2m}\right]\delta(c_i, c_j) \tag{7}$$

$$m = \frac{1}{2}\sum_{i,j} w_{ij} \tag{8}$$

W_{ij} represents the weight value between node *i* and *j*; s_i and s_j represent the strength value of node *i* and *j* respectively; c_i and c_j represent

the modular to which node *i* and *j* belong respectively; and the value of $\delta(c_i, c_j)$ is 1 if they belong to the same modular, and 0 otherwise.

3. Result and analysis

3.1. Role and status of countries in global mineral governance system

3.1.1. Results of the evaluation

The 40 international organizations involve a total of 122 countries, so the complex network contains a total of 122 nodes as well as 4769 edges, as depicted in Fig. 3 (in order to ensure the readability of the picture, the abbreviation of the country is used in all the pictures when analyzing in this paper, and the corresponding full name of the countries is shown in Table 2 of the Appendix). The strength, betweenness centrality and closeness centrality values of each node are displayed in Fig. 4, the horizontal and vertical coordinates of the points represent the betweenness centrality value and closeness centrality value of the country, respectively, and the size of the points represent the strength value of the country, and the color of the points represent the importance of the country in the network. Combining the definitions of each indicator given above, from the point of view of strength, the European countries, the United States, Canada, Australia, and Brazil, India, and Russia have higher strength values, reflecting the fact that these countries participate in a larger number of international organizations. However, in terms of betweenness centrality and closeness centrality, non-developed countries such as Brazil, Mexico, India, and South Africa have higher values, indicating these countries serve as key intermediaries and have a more diversified capacity for cooperation.

Then, the board member information of each organization was counted and the countries they belong to were sorted out. On this basis, the quantity of organizations in which each country serves as a board member was plotted as a bar chart, as shown in Fig. 5. It should be noted that due to the large number of countries, countries that serve as board members in only 1–2 organizations are excluded from this paper in order to ensure readability of the picture. In summary, in conjunction with the importance of countries in the network, we can analyze the role and status of countries in the global mineral governance system.

Based on the evaluation results of the above indicators, countries participating in the governance can be classified into four distinct categories: countries with strong cooperative capacity and dominant capacity, countries with strong cooperative capacity but weak dominant capacity, countries with weak cooperative capacity but strong dominant capacity, and countries with weak cooperative capacity and dominant capacity.

Firstly, countries with strong cooperative capacity and dominant capacity include the UK, France, Germany, Sweden and Canada. The UK's high nodal importance and the quantity of organizations in which it serves as a board member suggest that it is not only active in the organizations, but also able to be the core setter of the rules and strategic direction of the organizations, and is a country with both cooperation and dominant capacity in the governance system. France, Germany and Sweden are second to the UK in the governance system and also exhibit high nodal importance and board membership. Canada has a high importance in the network by virtue of its high intermediation and also occupies a more central position by serving as a board member in several organizations.

Secondly, countries with strong cooperative capacity but weak dominant capacity mainly include Brazil, Mexico, South Africa, Russia and India, which are mostly less developed countries but emerging economies. These countries demonstrate certain importance in the network by virtue of their high intermediation or cooperation efficiency and their high motivation to participate, but they do not

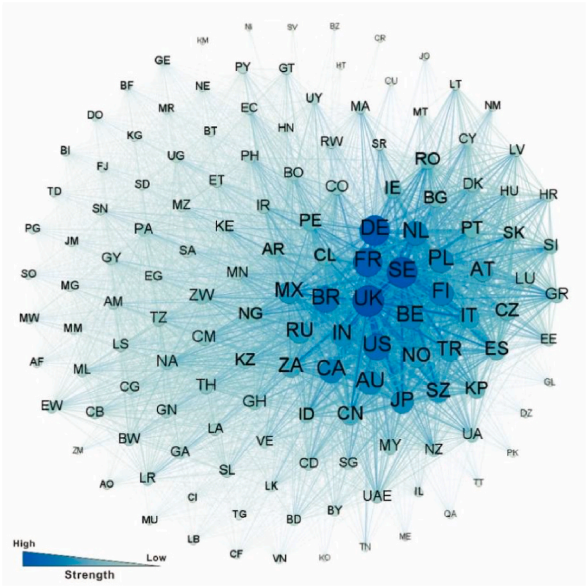

Fig. 3. National cooperation network based on international organizations.

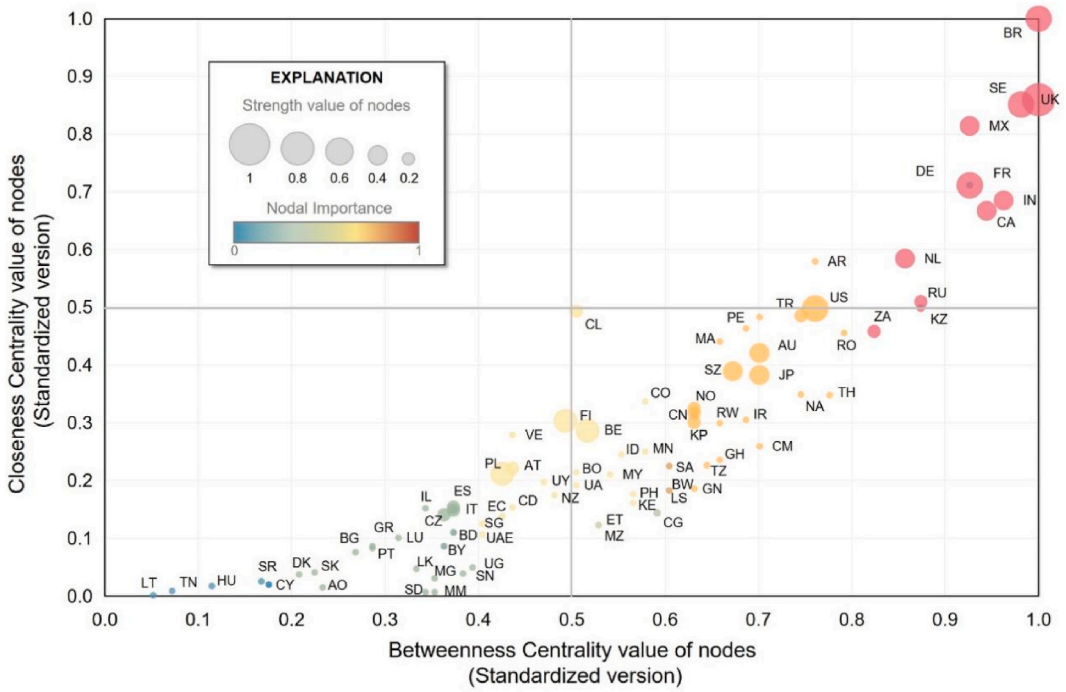

Fig. 4. Results of the evaluation of the importance of nodes.

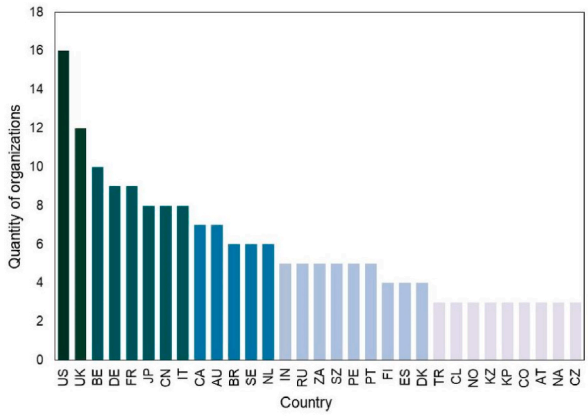

Fig. 5. Quantities of organization with country serving as board member.

have a strong dominant capacity due to low quantity of organizations in whom they as board of directors.

Then, countries with weak cooperative capacity but strong dominant capacity include mainly the U.S. and China. These countries have low importance in the cooperation network due to their low intermediation or active participation. However, their strong geopolitical power often allows them to play a dominant role in the strategy formulation of the organizations in which they participate by serving as board members in the organizations.

Finally, countries with weak cooperative and dominant capacity include mainly African, South American and some European countries. They are marginalized in the governance system because of their low motivation or cooperation capacity to participate in governance and their inability to demonstrate a certain level of leadership in the organization.

3.1.2. Analysis combined with reality

3.1.2.1. Countries with strong capacity for cooperation and dominance. European countries are the early pioneers in global governance, having constructed a series of international systems through rules and orders, and using their long-accumulated experience in system to dominate global governance in cooperation with authoritative international organizations such as the WTO, the G7, the World Bank

[37]. Concurrently, Europe is also a region with shortcomings in mineral resource endowment, with limited production of metal products, and the rapid development of economy and science and technology has led to a serious degree of external dependence on some of its mineral resources. Therefore, in order to reduce the supply risk of mineral resources and maintain its role as an exporter of manufacturing goods, European countries have taken advantage of their pre-eminence in global governance to actively participate in or lead the establishment of relevant international organizations in the fields of trade and investment in mineral resources, responsible mining, and mineral information networks, in order to safeguard and strengthen the global mineral governance system that is conducive to the security of their resources. Among them, the UK, France, Germany, and Sweden have stronger comprehensive power and a higher degree of external resource dependence due to rapid developments in economy and technology. They concern not only about the security of resource supply, but also about transparency in the supply chain. Therefore, in the global governance system, through the establishment of multilateral cooperative relationships with supplier countries with a high degree of economic development, such as Canada and Australia, as well as with conflict-prone supplier countries in Africa and South America, such as Peru, Chile and South Africa, in the areas of minerals' free trade and formulation of industry standards, as shown in Fig. 6 (a). Not only show a stronger willingness to dominate, but also show a stronger dominant ability to take up the core status in the governance system.

Canada is a globally important supplier of mineral resources and a developed country with a high degree of economic development and political stability. With its advanced mining exploration technology and mature financing market, Canada occupies a central status in the global mineral governance system. It has not only initiated inter-Country mining alliances, but has also joined various international organizations and established multilateral cooperation with other countries in order to jointly address the various problems in the mining market, as shown in Fig. 6 (b). By virtue of its high intermediation and cooperation efficiency, it holds a certain advantage in the national cooperation network, and also plays a leading role in the establishment of international organizations and policy formulation, bolstered by its strong economic and political power.

3.1.2.2. Countries with strong capacity for cooperation but weak capacity for dominance. Brazil, Mexico, Russia, South Africa and India are highly endowed with mineral resources, and the reserves of a variety of mineral resources rank among the world's highest, such as niobium and tantalum in Brazil, platinum group metals in South Africa, and copper, lead and zinc in Mexico, and so on. The mining industry plays a vital role in their economic development but also brings about a host of economic, social, and political challenges. To address these issues, on the one hand, these countries have joined market research groups or alliances for minerals' supply to discuss production, trade, price and other issues related to mineral resources with consumer countries; on the other hand, as important suppliers of mineral resources, these countries are bound to face a series of issues related to responsible and sustainable exploitation of mineral resources, such as human rights violations, environmental pollution, gender inequality, and corruption in the industry. Therefore, they have cooperated with each other or with African and South American countries that are facing the same problems to solve the above problems. As a result, these countries not only exhibit high strength values in the cooperation network, but also have high values of betweenness centrality and closeness centrality due to the diversity of the countries that cooperate, as shown in Fig. 7. However, due to their lesser economic power and political status than developed countries such as European and the U.S., also their relative lack of experience and dominant capacity in the field of global governance, mean they have demonstrated weaker dominant capacity in the organizations.

3.1.2.3. Countries with weak capacity for cooperation but strong capacity for dominance. The U.S. stands as one of the world's foremost producers, consumers, and traders of mineral resources. However, due to the exploration costs, environmental pollution and

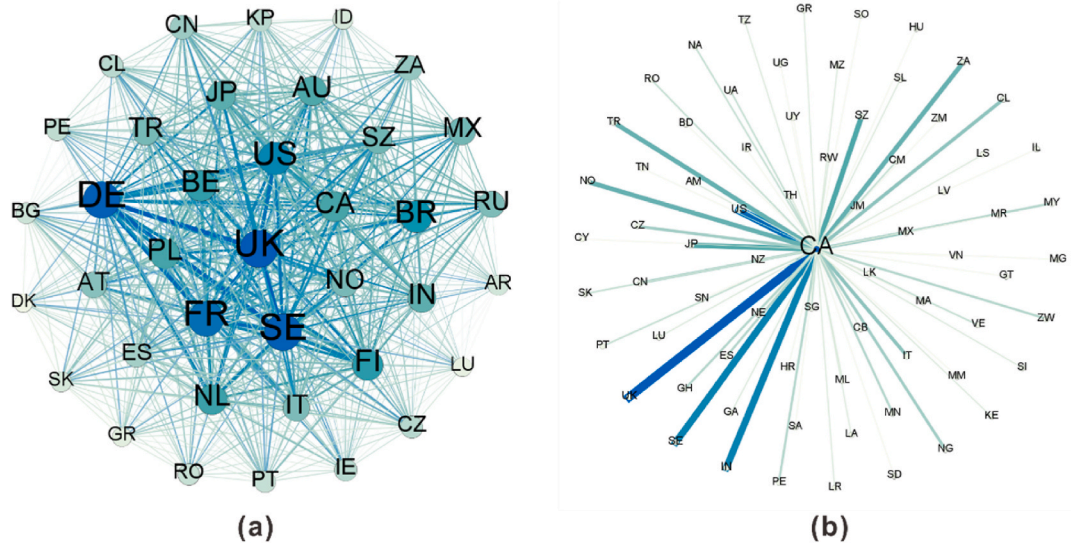

Fig. 6. The national cooperation network of European Countries (a) and Canada (b).

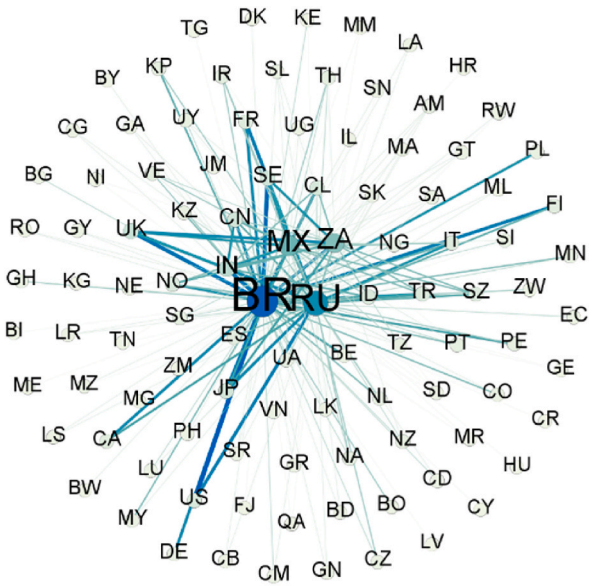

Fig. 7. The national cooperation network of Brazil, Russia, India and Mexico.

protection of local resources and other factors, the U.S. is highly dependent on imports to obtain most of the mineral products. According to USGS statistics, in 2020, the U.S. has a total of 63 kinds of mineral products with a foreign dependence of more than 20 %, of which 47 kinds exceed 50 % and 17 kinds reach 100 %. Most of these highly import-dependent minerals are integral to both the U.S. economy and national security [38], so the U.S. has consistently pushed to ensure the security of its minerals supply and the sustainable development of related industries through strategic initiatives with allies and partners, such as the launch of the Energy Resource Governance Initiative (ERGI), the Mineral Security Partnership (MSP), and the Alliance for Sustainable Critical Minerals (ASCM), which is a coalition of allies that share their experience in extracting minerals with other countries, and creates a "Critical Minerals Community" with allied countries to establish a sustainable and resilient supply chain and to ensure the secure supply of critical minerals for its strategic emerging industries and clean energy transition [39], which is reflected in the high strength value of the U.S. However, the main factor contributing to the relatively limited cooperative capacity of the U.S. is the low level of intermediation and efficiency within the cooperation network. Most of the countries with strong ties to the U.S. are allies with whom the U.S. has established long-term cooperation and maintained interests, including European countries with similar aspirations to the U.S. and the same pursuit of security of mineral supply, as well as resource-producing countries such as Canada, Australia, Peru and so on. There are also BRICS countries such as China, Russia, and Brazil, while closer cooperation has not been established with most African and

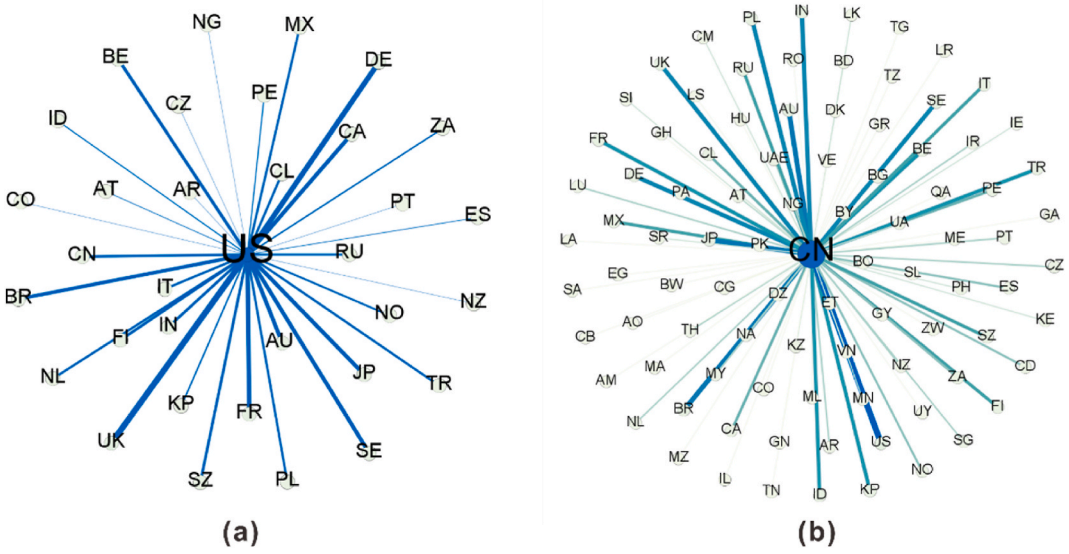

Fig. 8. The national cooperation network of the U.S.(a) and China(b).

South American countries, resulting in a less diverse set of partner countries, as illustrated in Fig. 8 (a). In terms of dominant capacity, the U.S. is committed to becoming the main promoter of the global mineral governance as well as consolidating its right to speak in the global mining market, so it usually acts as a central role to dominate the strategic direction of the organization. Thus, although cooperative ability of the U.S. is relatively weaker, it still exhibits the strongest dominant capacity.

In contrast, China's rapid development since the Reform and Opening-up, the comprehensive national power has been significantly enhanced, and the improvement of the industrial system has driven the rapid growth of domestic mineral resources consumption, which has become the world's number one production, consumption and trade country of mineral resources [1]. Concurrently, with the rapid development of strategic emerging industries, the external dependence of some shortage minerals has further increased with the growth of consumption, exacerbating the supply risk. Therefore, China needs to seek a rational allocation of mineral resources through participating in global governance to address key issues such as resource security and the sustainable development of related industries. However, compared with European and North American countries, China lacks rich experience in global governance, and its participation in the actual governance system is relatively low, resulting in lower levels of participation and less diverse international collaborations, as shown in Fig. 8 (b). This is inconsistent with China's status as a major mineral resources country, and is also a deficiency in China's participation in global mining governance [40]. However, in the organizations it has joined, China is often able to serve as a member of the board of directors, playing a certain leading role in the organization, or through authoritative international organizations such as APEC and RCEP, which it has joined, to solve various problems in the global mining market, to achieve a balanced allocation of global mineral resources, and to foster the development of the market.

3.1.2.4. Countries with weak capacity for cooperation and dominance. As a consequence of the development model of regional integration, there are stronger links between European countries [41], which is manifested in the fact that the quantity of organizations co-occurring among European countries is much higher. Unlike countries with strong comprehensive power such as the UK, Germany and France, some European countries, such as Denmark, Poland, Finland, the Czech Republic, with a relatively low degree of industrial development and relatively weak scientific and technological innovation capacity, are more focused on intra-European organization governance, and strive to maximize the efficiency of their own resource production and utilization through the governance model of regional integration. Therefore, although these countries are more active in participating in the organization, their intermediation and efficiency within the cooperation network are limited, resulting in a relatively weak cooperative capacity. At the same time, because these countries are more focused on intra-European regional governance, they also do not show a strong dominant capacity in international organizations.

Additionally, most African and South American countries have low global economic power and political standing, and do not have a voice and competitiveness in the global mining market, at the same time, the stage of economic development determines make these countries have a limited willingness to participate in global governance, and do not have sufficient capital strength and governance capacity to be integrated into the current governance system, rendering them weak in both cooperative and dominant capacities.

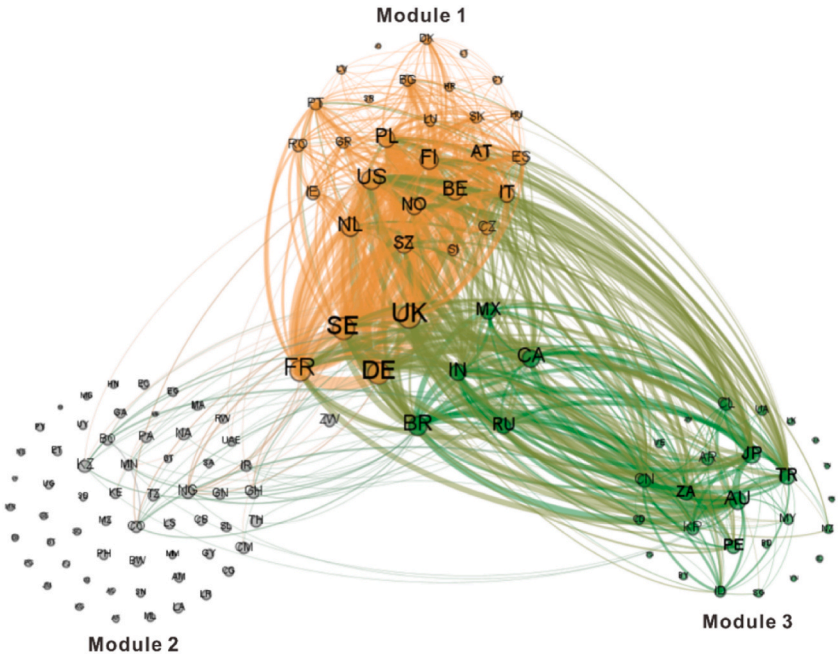

Fig. 9. The classification of national community.

3.2. National community in the global mineral governance system

3.2.1. Results of the classification of national community

The modularity value of the network was computed to be 0.329, signifying a well-defined community structure within the network According to the closeness of the edges between nodes, the countries in the network are segregated into three communities. In order to highlight the important cooperative relationships in the network, we delete the edges with co-occurring organizations less than 3, and places the nodes with high intermediation in the center of the graph, which is shown in Fig. 9. It can be seen that developed countries such as European countries and the U.S., which are also consumer countries of mineral resources, are in the first community. Mineral resource producer countries like Canada, Australia, Peru, Chile, as well as the China, Brazil, Russia, South Africa and India are in the second community, and most South American and African countries are in the third community.

3.2.2. Factors influencing the classification of national community

As previously delineated, factors such as economic development, political stability, and mineral resource endowment play pivotal roles in shaping a country's standing within the global governance framework. However, whether these factors can be used as the basis for the division of network communities, needs to be further explored. In this regard, we further analyze the common characteristics of countries within the same community in terms of their economic development, political stability, and mineral production capacity, in order to explore the underlying reasons for the division of community. The level of economic development is quantitatively assessed by a country's GDP per capita. The degree of political stability is evaluated by the World Governance Index (WGI), which comprehensively evaluates through the six dimensions of more public discourse and stronger government accountability, higher political stability and less social violence, higher government effectiveness, higher quality of regulation, better rule of law, and less corruption. A lower WGI score indicates a higher degree of political stability of the country. The production capacity of minerals is expressed by the mining output value, due to the large difference in the value of each country, in order to be able to clearly display in the coordinate system, the data of mining output value is standardized within a 0 to 1 range. The data source of the World Governance Index (WGI) and GDP per capita data is the World Bank, and the mining output value data is obtained from the report *World Mining Data 2020*, which was jointly published by the World Mining Congress and the Austrian Federal Ministry. It is imperative to note that due to the impact of the COVID-19, the economic growth, political stability and industrial development of each country in 2020 may deviate from the actual level. To ensure the reasonableness of the research results, we adopt the data in 2019. Based on the availability of data, a three-dimensional scatterplot has been drawn, as shown in Fig. 10.

After conducting a quantitative assessment, it was found that countries belonging to the same community do have similar economic, political and mineral resource endowment characteristics. The European countries and the U.S. in the first community have high economic development and political stability, but low mineral resource endowment and are import-dependent countries, so based on the same demand and in order to ensure a stable supply of minerals, these countries have established close ties through the formation of alliances, such as the joint establishment of the Critical Raw Materials Alliance (CMA), and the joint agreement for U.S.-European critical minerals.

Although the levels of economic and political development are not very similar, most of the countries in the second community are highly endowed with mineral resources and are resource-exporting countries, such as lithium in Argentina and Chile, copper in Peru, iron in Australia, and niobium and tantalum in Brazil. Among them, Canada and Australia have higher levels of economic development and political stability. The remaining countries, including the BRICS nations and certain African and South American countries, differ significantly from developed nations in their economic and political landscapes. These countries have established close cooperation

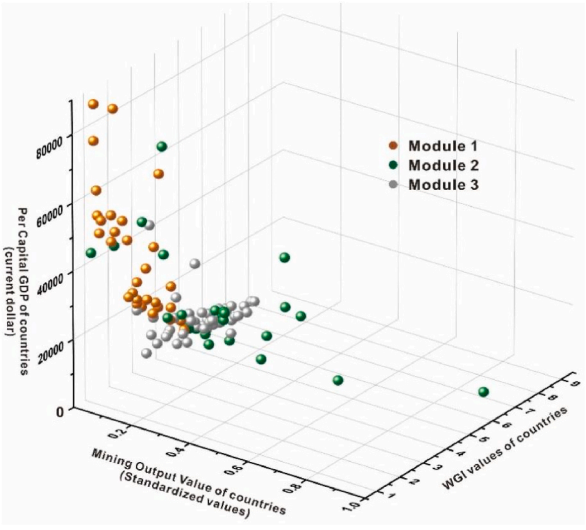

Fig. 10. A three-dimensional scatterplot of influencing factors.

through joint participation in or spontaneous establishment of organizations based on the same demands, such as solving the environmental, human rights and other sustainable development problems arising from resource exploitation, as well as the problem of stable supply of resources.

The countries in the third community are all African and South American countries, most of which belong to the category of countries with low levels of economic development and political stability, as well as limited resource endowments. Although certain countries, such as the Democratic Republic of the Congo and Zimbabwe, have high production for some minerals like cobalt and gold, their poor geopolitical situation has prevented them from becoming central players in the governance system, and they have been marginalized.

Furthermore, based on the edge weights between nodes, we also find that the cooperation between the first and second community is very close. Combined with the actual situation of the mining market can be interpreted as, due to Canada, Australia, the BRICS countries have relatively good mineral resource endowment, especially the critical minerals to support the development of strategic emerging industries and the transformation of clean energy, such as China's rare earths, Canada's nickel, Australia's lithium, South Africa's platinum group and so on. Therefore, the European countries and the U.S., import-dependent countries, cooperate closely with the above countries by trading, investing and establishing alliance, in order to ensure the stable supply of minerals and the liberalization of investment and trade, and to jointly address economic, social and sustainable development issues related to mineral resources, while at the same time enhancing their own supply resilience and avoiding the supply risks posed by barriers to trade in mineral resources, enhancing their own control over the supply and utilizing their international authority to use global governance as a tool to guarantee their resource security.

4. Limitation and future research

First of all, in this research, we have assumed that all organizations have the same importance. However, in fact, some organizations may hold important discourse power in the global governance system, and when the country joins these organizations, the weight of the country rises, and the results of the analysis on the role and status of the country may be different. To address this limitation, future research endeavors will incorporate the relative importance of international organizations. We plan to identify pertinent indicators to assess the significance of these organizations and use these metrics as a basis for discussing the capacity of the countries in the organizations.

Second, in this research, we have analyzed the structure of the current governance system by current organizations. However, in fact, according to the establishment time of international organizations, a time series analysis can be carried out. From the early days to the present, the construction of national cooperation networks for some time periods can be used to analyze which countries participated in the governance in the early days, and which countries joined later as the demand for mineral resources grew or the economy developed, so as to provide a more in-depth understanding of the structure of the governance system. To achieve this, our research will apply the research method of text mining to comprehensively collect and sort out the historical information of mineral related organizations, establish a time series, and explore the evolution of the structure of the governance system.

5. Conclusion

(1) The mineral resource consuming countries (The UK, Germany, France, Sweden), and the mineral resource producing country (Canada): These countries with a higher level of economic and political development, are of higher importance in the cooperation network, while the stronger geopolitical power gives these countries a certain dominant capacity in international organizations. It has a role in promoting international cooperation as well as leading governance.
(2) The emerging economies (Brazil, Mexico, Russia, India, and South Africa): These countries are significant in the cooperation network due to their status as mineral resource producers. However, their current economic and political standing limits their ability to lead in international organizations. As these countries continue to develop, their roles in the governance system are likely to become more prominent.
(3) The U.S. and China: The intermediary of the U.S. and motivation to participate of China in countries' cooperation are low, resulting in both being less important in cooperation networks but more dominant in the organizations, driven by geopolitical power.
(4) Most African and South American Countries: These nations generally exhibit a low willingness to engage in global mineral governance. Their economic and political limitations further hinder their ability to assume leadership roles in international organizations.
(5) Some European Countries (Finland, Denmark, Poland): These countries primarily focus on governance within Europe and have limited capacity to influence global governance. Their roles are thus more localized and less impactful on a global scale.
(6) Community Division: The countries involved in global governance are divided into three communities. European countries and the U.S., consumer countries with high levels of economic and political development but low mineral resource endowments, are in the first community. Canada, Australia, the BRICS countries, Chile and Peru, producing countries with high mineral resource endowments, are in the second community. Most African and South American countries with low levels of economic and political development are in the third community. In addition, close links have been established between the first and second communities in order to ensure resource security.

Data availability statement

Data will be made available on request.

Ethics declarations

Review and approval by an ethics committee was not needed for this study because our methodology is mainly for data collection on the Internet without any experimental as well as unethical content.

Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Xiaojing Yuan: Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Zhe Ma:** Supervision, Project administration, Methodology. **Anjian Wang:** Supervision, Project administration. **Tianjiao Li:** Methodology. **Weiqiong Zhong:** Methodology. **Bujie Li:** Writing – review & editing. **Pengyuan Li:** Methodology. **Jiangqiao Wei:** Methodology. **Hongchang Hao:** Data curation.

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.

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Appendix

Table. 1
The international organization to which this article relates

Acronym	Name
AMGC	African Minerals and Geosciences Center
ARPP	Agreement on the Resolution of Practical Problems with Respect to Deep Seabed Mining Areas
ARM	Alliance for Responsible Mining
AFMA	ASEAN Federation of Mining Associations
ACRSRM	Association of Cities and Regions for Sustainable Resource Management
CRIRSCO	Committee for Mineral Reserves International Reporting Standards
ECOLEX	Convention on Civil Liability for Oil Pollution Damage Resulting from Exploration for and Exploitation of Seabed Mineral Resources
CCMAPM	Convention on the Control and Marking of Articles of Precious Metals
CRAMRA	Convention on the Regulation of Antarctic Mineral Resource Activities
CEEMET	Council of European Employers of the Metal, Engineering and Technology-Based Industries
CRMA	Critical Raw Materials Alliance
EITI	Extractive Industries Transparency Initiative
Euromines	European Association of Mining Industries, Metal Ores and Industrial Minerals
ENFMA	European non-ferrous metals association
EPRM	European Partnership for Responsible Minerals
EPMF	European Precious Metals Federation
ERMA	European Raw Materials Alliance
ERIC	European Recycling Industries' Confederation
ETPSMTR	European Technology Platform on Sustainable Mineral Resources
IGF	Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development
ICSG	International Copper Study Group
ICMM	International Council on Mining & Metals
IIMA	International Iron Metallics Association
ILZSG	International Lead & Zinc Study Group
IMMS	International Marine Minerals Society

(*continued on next page*)

Table. 1 (*continued*)

Acronym	Name
INSG	International nickel study group
IPGMA	International Platinum Group Metals Association
IRP	International Resource Panel
ITA	International Tin Association
IWM	International Women in Mining
IJO	Interoceanmetal Joint Organization
KPCS	Kimberley Process
LAMMP	Latin American Mining Monitoring Programme
MIASA	Mining Industry Association of Southern Africa
MMTA	Minor Metals Trade Association
NRGI	Natural Resource Governance Institute
SGA	Society for Geology Applied to Mineral Deposits
WMC	World Mining Congress
WRI	World Resources Institute
WSA	World Steel Association
WTO	World Trade Organization
G7	Group of Seven
G20	Group of Twenty
ICSID	The International Center for Settlement of Investment Disputes
RCEP	Regional Comprehensive Economic Partnership
TPP	*Trans*-Pacific Partnership Agreement
UNGC	United Nations Global Compact
OECD-GME	OECD Guidelines for Multinational Enterprises
CAREC	The Central Asia Regional Economic Cooperation
APEC	Asia-Pacific Economic Cooperation
World Bank	World Bank
UNEP	United Nations Environment Program

Table. 2
The abbreviations of countries

Country	Abbreviation	Country	Abbreviation
Afghanistan	AF	Lithuania	LT
Algeria	DZ	Luxembourg	LU
Angola	AO	Madagascar	MG
Argentina	AR	Malaysia	MY
Armenia	AM	Mali	ML
Australia	AU	Mauritania	MR
Austria	AT	Mexico	MX
Bangladesh	BD	Mongolia	MN
Belarus	BY	Montenegro	ME
Belgium	BE	Morocco	MA
Bhutan	BT	Mozambique	MZ
Bolivia	BO	Myanmar	MM
Botswana	BW	Namibia	NA
Brazil	BR	Netherlands	NL
Bulgaria	BG	New Zealand	NZ
Burundi	BI	Nicaragua	NI
Cambodia	CB	Niger	NE
Cameroon	CM	Nigeria	NG
Canada	CA	Norway	NO
Chile	CL	Pakistan	PK
China	CN	Panama	PA
Colombia	CO	Papua New Guinea	PG
Congo	CG	Paraguay	PY
Congo(k)	CD	Peru	PE
Costa Rica	CR	Philippines	PH
Croatia	HR	Poland	PL
Cyprus	CY	Portugal	PT
Czech Republic	CZ	Qatar	QA
Denmark	DK	Romania	RO
Ecuador	EC	Russia	RU
Egypt	EG	Rwanda	RW
Ethiopia	ET	Saudi Arabia	SA
Fiji	FJ	Senegal	SN
Finland	FI	Serbia	SR
France	FR	Sierra Leone	SL
Gabon	GA	Singapore	SG
Georgia	GE	Slovakia	SK

(*continued on next page*)

Table. 2 (*continued*)

Country	Abbreviation	Country	Abbreviation
Germany	DE	Slovenia	SI
Ghana	GH	Somalia	SO
Greece	GR	South Africa	ZA
Guatemala	GT	South Korea	KP
Guinea	GN	Spain	ES
Guyana	GY	Sri Lanka	LK
Honduras	HN	Sudan	SD
Hungary	HU	Sweden	SE
India	IN	Switzerland	SZ
Indonesia	ID	Tanzania	TZ
Iran	IR	Thailand	TH
Ireland	IE	Togo	TG
Israel	IL	Tunisia	TN
Italy	IT	Turkey	TR
Jamaica	JM	UAE	UAE
Japan	JP	Uganda	UG
Jordan	JO	Ukraine	UA
Kazakhstan	KZ	United Kingdom	UK
Kenya	KE	Uruguay	UY
Kyrgyz Republic	KG	United States of America	U·S.
Laos	LA	Venezuela	VE
Latvia	LV	Vietnam	VN
Lesotho	LS	Zambia	ZM
Liberia	LR	Zimbabwe	ZW

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