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Risk assessment of oil and gas investment environment in countries along the Belt and Road Initiative

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ABSTRACT

With the implementation of the Belt and Road Initiative, China is deepening its cooperation in oil and gas resources with countries along the Initiative. In order to better mitigate risks and enhance the safety of investments, it is of significant importance to research the oil and gas investment environment in these countries for China's overseas investment macro-layout. This paper proposes an indicator system including 27 indicators from 6 dimensions. On this basis, game theory models combined with global entropy method and analytic hierarchy process are applied to determine the combined weights, and the TOPSIS-GRA model is utilized to assess the risks of oil and gas investment in 76 countries along the Initiative from 2014 to 2021. Finally, the GM (1,1) model is employed to predict risk values for 2022 −2025. In conclusion, oil and gas resources and political factors have the greatest impact on investment environment risk, and 12 countries with greater investment potential are selected through cluster analysis in conjunction with the predicted results. The research findings may provide scientific decision-making recommendations for the Chinese government and oil enterprises to strengthen oil and gas investment cooperation with countries along the Belt and Road Initiative.

1. Introduction

The consumption of oil and natural gas in China continues to grow, while the nation's self-sufficiency in these resources is weak, resulting in a persistently high dependence on foreign sources. With the continuous development of China's economy, the demand for oil and gas is on an upward trend (as shown in Fig. 1), and in 2021, China's foreign dependence on oil and natural gas reached 72.2% and 46%, respectively. As a result, undertaking oil and gas investment cooperation and safeguarding energy supply security are crucial for China's economic development. The National Development and Reform Commission and the National Energy Administration jointly issued the "14th Five-Year Plan for Modern Energy System," which emphasizes the need to consolidate and expand overseas energy resource security capabilities and enhance import diversification and security capabilities. Since 1993, Chinese oil companies have adhered to the "going global" strategy, achieving a series of results in oil and gas exploration and development, yet China's overseas oil and gas investments still face immense challenges.

At present, China's overseas exploration faces the risks of shrinking equity block areas and expiring contracts. For oil and gas fields with a primary focus on purchasing reserves, blocks with successful independent exploration have lower costs per barrel and higher benefits, making the success of independent exploration crucial for overseas oil and gas projects (Dou et al., 2022a, 2022b). Taking China National Petroleum Corporation, which has the largest number of overseas exploration blocks, as an example, the exploration block area during the peak years of 2007−2008 exceeded, while only remaining by the end of the 13th Five-Year Plan, far below the level of major international companies.

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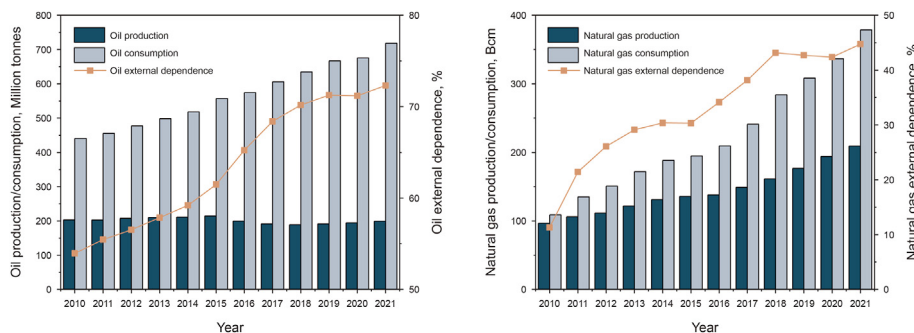*E-mail address:* tbj@bit.edu.cn (B.-J. Tang).

Fig. 1. China's oil and gas supply and demand trends.

Moreover, after reaching peak equity production of oil and natural gas in 2029, the overseas oil and gas production of the three major oil companies will decline sharply by 2035, and by 2040, equity production of oil and natural gas will be 35% and 54% of peak production, respectively (Dou et al., 2022a). Therefore, China needs to acquire a significant number of new projects in the future to maintain oil and gas production. Additionally, China's overseas exploration is adversely affected by the economic recession brought about by the COVID-19 pandemic, exacerbated trade protectionism, and other negative factors, significantly impacting oil and gas enterprises' overseas investments. Furthermore, there are notable differences in the oil and gas investment potential of resource-rich countries, with some facing obstacles from finance, policy, and geopolitics.

Since President Xi Jinping proposed the Belt and Road Initiative (BRI) in 2013, the countries along the initiative have gradually become the core oil and gas cooperation zones for Chinese oil enterprises overseas. Russia, Western Asia, and the Middle East, situated in the world's "Oil Heartland," all lie within the scope of the Belt and Road Initiative, with the oil and gas production of countries along the Initiative accounting for over 60% of the world's total oil and gas production (Zhao et al., 2021). Therefore, assessing the risk of oil and gas investment environments in countries along the Belt and Road Initiative is of considerable importance for the macro-layout of overseas investments by Chinese oil enterprises in order to better mitigate risks and enhance investment safety. This paper is organized as follows: Section 2 provides a literature review, Section 3 details the methods and data, Section 4 presents the research process and results analysis, and Section 5 concludes with recommendations.

2. Literature review

Overseas oil and gas investment environment risk assessment research mainly focuses on risk identification and risk model construction. In terms of risk factor identification, there are many rating agencies worldwide that have conducted professional ratings and analyses of investment risks by constructing indicator systems. China's Academy of Social Sciences releases the "China Overseas Investment Country Risk Rating Report" every year (Zhang and Wang, 2018), analyzing macro investment risks of various countries from five aspects: economic foundation, political risk, China relations, social resilience, and debt repayment ability. The International Country Risk Guide (ICRG) released annually by the US International Reports Group evaluates 140 countries comprehensively through three types of risk indicators (e.g. political risk, financial risk, and economic risk) and their 22 variables (The PRS Group, 2023). However, these indicator systems are only applicable to national macro investment environments and do not

consider the characteristics of the oil and gas industry. In constructing indicator systems for the oil and gas investment environment, the characteristics of oil and gas investment projects should be fully considered. Among the domestic and international indicator systems focusing on energy investment, the Fraser Institute proposes a mining investment environment evaluation system that mainly evaluates the potential policy index; the Behre Dolbear company proposes an oil investment environment evaluation system that mainly evaluates the political risks affecting investment; China's Ministry of Land and Resources' "Global Mining Investment Environment Evaluation" considers investment environment from the aspects of accessibility of foreign investment in mining, investment security, and profitability (Chen et al., 2014); and Information Handling Services (IHS) builds an oil and gas exploration and exploitation attractiveness rankings from multiple perspectives such as politics, economy, oil and gas resources, and contracts. Generally speaking, the current construction of indicator systems mainly considers the impact of oil and gas resource risks (Zhou et al., 2020), economic risks (Hussain et al., 2020; Tang et al., 2018), and political risks (Chen et al., 2016, 2021), and some research includes environmental constraints for more comprehensive analysis (Li et al., 2020; Hussain et al., 2020). However, although these indicator systems consider the specificity of oil and gas investment projects, they do not fully examine the bilateral relations between China and resource countries, resulting in limited reference value for Chinese oil enterprises to carry out overseas oil and gas investment.

Existing literature classifies the methods used in risk assessment into three categories: qualitative, quantitative, and integrated. In the early stages of overseas investment risk assessment, scholars often used qualitative research methods. Later, scholars began to adopt more scientific quantitative methods for research: Tafur et al. (2022) use AHP (Analytic Hierarchy Process) and TOPISIS (Technique for Order Preference by Similarity to an Ideal Solution) methods for comprehensive ranking of investment risks in the upstream oil sector of South American countries; Duan et al. (2018) evaluate overseas energy investment by a fuzzy integrated evaluation model based on the entropy weight. Zhao et al. (2021) rank the oil and gas resource cooperation of 28 countries along the BRI through an improved entropy-weighted TOPSIS method and use cluster analysis to divide the cooperation risks into four levels; Duan et al. (2021) apply the cloud parameter Bayesian network algorithm for dynamic assessment of oil and gas overseas investment risks in 10 countries. In recent years, to minimize the impact of "inconsistency of conclusions in multiple methods," evaluation methods tend to be combined. Yang (2020) combines the AHP fuzzy comprehensive evaluation method, principal component analysis method, entropy weight method and improved fuzzy borda to evaluate the investment environment of overseas oil and gas

exploration and development; Wang and Ding (2017) construct an optimal weighted combined evaluation model of oil and gas investment environment based on seven single evaluation models.

Overall, existing research on the risk assessment of overseas investment environment still needs further improvement. First, in terms of the construction of overseas oil and gas investment systems, existing research lacks consideration of the overseas oil and gas investment environment from a Chinese perspective. Moreover, most research mainly revolve around the analysis of geopolitical risks in resource countries, with less consideration for bilateral political relations, economic aspects of oil and gas contracts, etc. Second, in terms of evaluation methods, most literature still adopt single evaluation methods for oil and gas investment environment risks, making it difficult to ensure the rationality of evaluation conclusions. Third, oil and gas investment projects are long-term investments, and the research should fully consider the time span. Current research mainly focuses on the horizontal comparison or ranking of the oil and gas investment environment in different countries, with relatively less longitudinal comparison, making it difficult to reflect the changing trend of oil and gas investment risks intuitively. Lastly, current research lack predictions about the future development of the oil and gas investment environment, with only a few scholars analyzing development trends from a theoretical level.

Considering the limitations of existing literature, the key contributions of this paper are: (1) It improves the oil and gas investment environment risk assessment indicator system. By considering risk factors that measure bilateral relations, the article enhances the model's alignment with Chinese enterprises' overseas oil and gas investments, ultimately constructing an oil and gas investment environment risk assessment indicator system that includes five primary indicators and 27 secondary indicators. (2) It establishes a comprehensive evaluation model of the oil and gas investment environment for countries along the BRI. Based on global entropy value, analytic hierarchy process (AHP), TOPSIS model, and GRA model, the study constructs a combined evaluation model to address the inconsistency of evaluation results caused by single evaluation methods. (3) It analyzes the dynamic evolution of oil and gas investment environment risks in countries along the BRI based on data from 2014 to 2021. (4) Using the grey prediction model, the article conducts short-term forecasts of the comprehensive risk values for each country from 2022 to 2025, providing a scientific basis for the future overseas oil and gas investment location selection of Chinese oil enterprises. (5) It carries out cluster analysis on preferred resource countries and proposes differentiated strategies for countries with different risk characteristics.

3. Methods and data

In this section, an indicator system is constructed firstly, and then we calculate the indicator weight by the game theory weighting model, which considers AHP and the global entropy method at the same time. Thirdly, it identifies the oil and gas investment environment risks by an integrated evaluation model which combines TOPSIS and GRA. Fourthly, based on evaluated risk values, it utilizes the grey prediction model forecasting country-specific risk values from 2022 to 2025.

3.1. Construction of the indicator system

In this section, the indicator selection will be based on the literature analysis method, expert interview method, correlation analysis, and significant difference analysis to construct the risk assessment indicator system for the oil and gas investment environment in countries along the BRI. The construction process is shown in Fig. 2.

3.1.1. Preliminary results of indicator selection based on literature analysis and expert interview methods

This study draws on research by authoritative institutions in recent years and literature related to domestic and international oil and gas investments to initially formulate alternative plans for the oil and gas investment environment risk assessment indicator system. This primarily refers to investment evaluation systems published by authoritative institutions such as the Ministry of Land and Resources, Fraser Institute, mining consulting firm Behre Dolbear, U.S. International Reports Group, and the Chinese Academy of Social Sciences. By screening 37 literature pieces related to oil and gas investment environment risk assessment from domestic and foreign databases like CNKI and Web of Science, indicators used in the literature were classified and consolidated.[1] Finally, indicators were combed through in terms of economic factors, political factors, China factors, resource endowment, and business environment, preliminarily sorting out a candidate indicator system including five primary indicators and 72 secondary indicators.

Considering that too many indicators would not only increase the difficulty of data search and tracking but also make it difficult to compare different countries (Streimikiene and Sivickas, 2008), experts in the oil and gas field were invited to select indicators based on their industry research experience.[2] Additionally, since existing literature pays less attention to the Chinese perspective when studying the risk assessment of overseas oil and gas investment environments, some studies only measure Sino-foreign economic and trade relations from aspects such as import and export trade volume, oil and gas exports, and direct investment, without fully considering bilateral political relations (Yan et al., 2017). This paper refers to the "bilateral political relations" indicator in the "China Overseas Investment Country Risk Rating Report" published annually by the Chinese Academy of Social Sciences (Zhang and Wang, 2018), and invites experts in the oil and gas field to score the political relations between each BRI oil and gas resource country and China, with the average score as the "bilateral political relations" indicator. The scoring range is [1,10], with higher scores indicating better political relations between the country and China, and vice versa. Ultimately, 29 secondary indicators were retained, taking into account expert feedback and data availability.

3.1.2. Indicator selection results based on correlation analysis and significant difference analysis

In this section, the initially selected indicators are subjected to correlation analysis and significant difference analysis to avoid the repetition of information reflected by the indicators and ensure that the selected indicators have a significant impact on the evaluation results.

First, the correlation analysis results show that the correlation coefficients between the indices are mostly within the range of $[-0.5, 0.5]$, and the overall correlation between the indices is not very strong (see Fig. A1). However, the correlation coefficients between "government revenue," "internal rate of return for oil and gas contracts," and "net present value per barrel for investors" are all above 0.9, indicating a high degree of information duplication among the three, mainly because all three indicators are investment attractiveness rating indicators for oil and gas contract profitability on the IHS website, with highly similar evaluation angles. In addition, the correlation coefficient between "bilateral trade volume" and " total GDP " does not exceed 0.9, but the correlation between

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[1] The keywords when we search literature are (("oil investment" or "gas investment") and "risk assessment").

[2] Our experts are senior researchers from CNOOC and Sinopec, which is the top 20 oil company in the world.
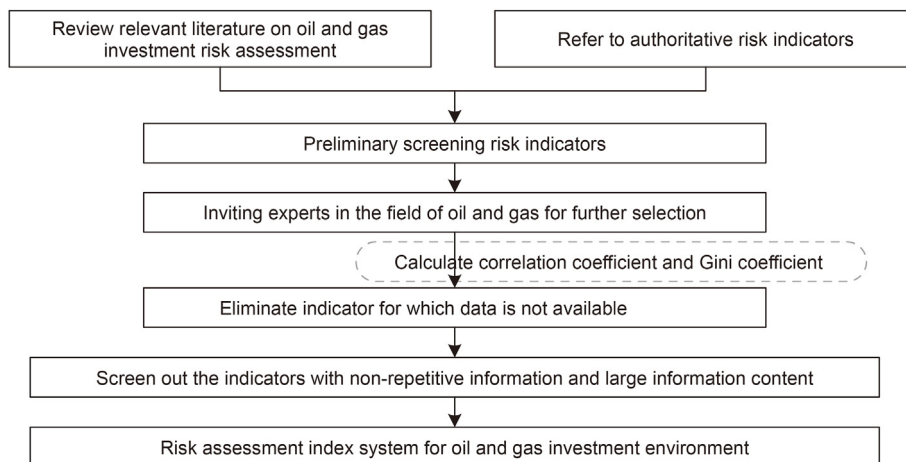
Fig. 2. Steps of indicator system construction.

the two indicators is still significant. This is mainly because the stronger a country's economic strength, the more active it will naturally be in the international trade market. Therefore, when constructing the indicator system, the ratio of "bilateral trade volume" to "total GDP", named as "bilateral economic and trade relations", is used as an indicator to measure the bilateral economic and trade relations between resource countries and China.

Secondly, the information reflected by the three indicators "government revenue," "internal rate of return for oil and gas contracts," and "net present value per barrel for investors" is repetitive. In order to retain the indicator with the most information content, these three indicators should be subjected to significant difference analysis, i.e., calculating the Gini coefficient between the indicators (Choudhury et al., 2020). The Gini coefficients of "government revenue," "internal rate of return for oil and gas contracts," and "net present value per barrel for investors" are 0.213, 0.184, and 0.194, respectively, indicating that the differences among resource countries in the "government revenue" indicator are large. The information content of this indicator is better than that of "internal rate of return for oil and gas contracts" and "net present value per barrel for investors." Therefore, "government revenue" should be retained, and the other two indicators should be removed to simplify the oil and gas investment environment risk assessment indicator system.

3.1.3. The indicator system for the evaluation of oil and gas investment risk

Based on the literature analysis method and expert interview method for sorting out indicators and further screening using correlation analysis and significant difference analysis, a risk assessment indicator system for the oil and gas investment environment, including five primary indicators and 27 secondary indicators, is eventually constructed (Fig. 3).

3.1.3.1. Political environment. Due to the generally long project cycle of oil and gas investments, a stable political situation plays a crucial role in China's oil and gas investment projects, making the political environment an important indicator for measuring the investment risk of oil and gas resource countries. This paper measures the political environment of resource countries through five sub-risk indicators: government stability, internal conflict, external conflict, corruption control, and the degree of democracy. Government stability is used to assess a country's government's execution ability of established plans and the stability of its regime;

internal conflict is used to evaluate political conflicts in a country and the actual and potential impacts they cause; external conflict is used to assess the risks posed by other countries to a country's government, including non-violent external pressures (such as diplomatic pressure, cutting off aid, trade restrictions, territorial disputes, sanctions, etc.) and violent external pressures (such as full-scale wars triggered by border conflicts, etc.); corruption control is used to evaluate the corruption level of a country's political system; the degree of democracy reflects the government's response to public demands.

3.1.3.2. Economic environment. Substantial capital flow is generated by oil and gas investments, and a robust economic environment provides support for these activities. Moreover, a well-developed economic system ensures the interests of investing countries and lowers investment risks. This study divides the economic environment risks into per capita GDP, GDP size, GDP growth rate, inflation risk, exchange rate risk, investment openness, and debt level. Per capita GDP, GDP size, and GDP growth rate are used to assess a country's economic development scale and potential. Inflation affects business operating costs significantly, and exchange rates introduce uncertainty in project financing costs. Therefore, evaluating resource-rich countries' inflation risk and exchange rate risk is essential. Investment openness is the ratio of a country's foreign direct investment to its GDP. For host countries engaged in international trade, a debt crisis would impact the investment security of investing countries. Consequently, the ratio of government debt to GDP is crucial in evaluating a country's financial burden capacity.

3.1.3.3. China factor. The success of Chinese oil companies' overseas investments relies heavily on the strength of diplomatic relations and the intensity of trade tensions. This study employs the China factor to measure the bilateral relationship between resource-rich countries and China, considering the perspective of overseas oil and gas investment risks from China. The China factor is measured through contracted foreign engineering projects, bilateral economic and trade relations, "Belt and Road" index, and bilateral political relations. "Belt and Road" index represents the year when resource-rich countries joined the BRI. The time at which countries along the Belt and Road joined the initiative varies due to a variety of factors such as their individual economic development, political environment, and diplomatic relations with China. Countries usually joined initiative earlier if they have closer
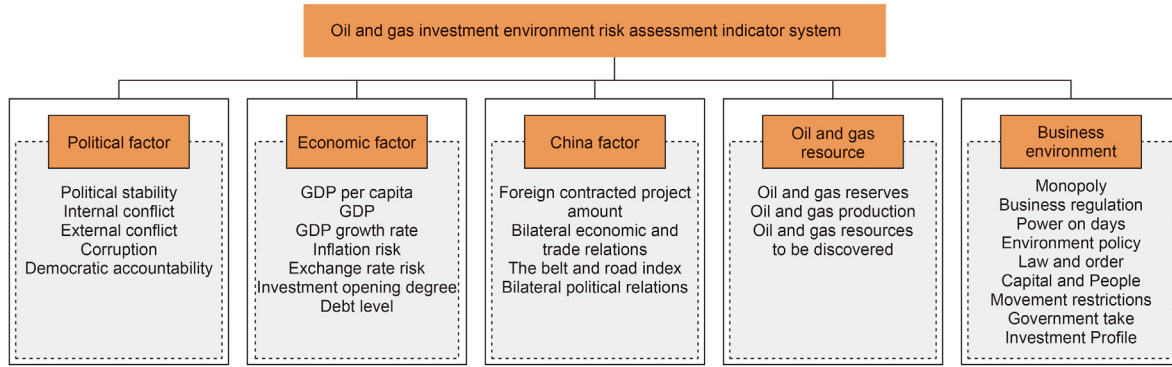
Fig. 3. Oil and gas investment environment risk assessment indicator system.

economic and diplomatic ties with China. Bilateral political relations are determined by expert assessments and scoring of political relationships between resource-rich countries and China in the oil and gas sector.

3.1.3.4. Resource endowment. Oil and gas resources form the foundation for investing countries' oil and gas investments in resource-rich countries. This study uses oil and gas reserves, production, and undiscovered resources to measure resource endowment risks. By evaluating the oil and gas resources in resource-rich countries, the study assesses the potential and stability of oil and gas extraction.

3.1.3.5. Business environment. The business environment primarily measures the market competition level and policy restrictions for Chinese companies investing in overseas oil and gas projects. The lower the degree of monopoly in resource-rich countries, the more favorable the conditions for conducting oil and gas investments. This is measured by the number of companies investing in oil and gas projects in the country. Waste emissions from resource development have long-term negative effects on the local environment. Therefore, environmental policy indicators are introduced to assess the constraints faced by investments due to environmental regulations (Dong et al., 2020). Access to electricity reflects the local infrastructure level. Business regulations, capital and personnel mobility restrictions, and the legal and social order represent the threshold and protection for investment enterprises in conducting business. Government income reflects the revenue risks associated with oil and gas contracts in resource-rich countries.

3.2. An Integrated evaluation model of oil and gas investment environment risk

3.2.1. Game theory combined weighting model to determine the indicator weight

3.2.1.1. Analytic hierarchy process. The analytic hierarchy process (AHP) is a qualitative and quantitative decision-making method that decomposes elements related to decision-making into objectives, criteria, and alternatives. The method boasts systematic, flexible, and concise advantages and is widely applied in various research fields (He et al., 2021; Keshavarzi et al., 2020). The core principle of AHP is to judge the importance of each risk factor in an oil and gas investment risk level relative to the previous risk factor and to represent the human subjective judgment in numerical form using a reasonable scaling method. The most commonly used scaling method is the 1−9 scale method, which forms the judgment matrix. Once the judgment matrix is formed, the maximum eigenvalue and its corresponding eigenvector can be calculated to obtain the relative importance weight value of a risk level for a particular risk element in the previous risk level.

3.2.1.2. Global entropy method. The entropy method is an objective weighting method based on the size of the information provided by the indicator observations to determine the weight of the indicators, typically using cross-sectional data for analysis. To dynamically analyze the oil and gas investment environment along the BRI countries, this study applies the global entropy method, introducing time series into the general cross-sectional data for dynamic risk assessment of the investment environment.

First, preprocess the raw data. For n resource countries and m evaluation indicators, establish an initial global evaluation matrix $\boldsymbol{A} = (x_{ij})_{m \times n}$. In the matrix, x_{ij} is the raw data of indicator j for resource country i. To eliminate the influence of indicator types and dimensions on the evaluation, normalize x_{ij} for easier indicator comparison. This study uses the extreme value method as the preprocessing method for its translation invariance, difference ratio invariance, and interval stability properties.

For positive indicators:

$$\frac{x_{ij} - \min\limits_{j} x_{ij}}{\max\limits_{j} x_{ij} - \min\limits_{j} x_{ij}} \tag{1}$$

For negative indicators:

$$\frac{\max\limits_{j} x_{ij} - x_{ij}}{\max\limits_{j} x_{ij} - \min\limits_{j} x_{ij}} \tag{2}$$

The normalized matrix $\boldsymbol{B}_{ij} = (y_{ij})_{m \times n}$ is obtained from Eqs. (1) and (2), where y_{ij} is the normalized data of the ith country's jth indicator.

On this basis, the characteristic proportions p_{ij}^t of y_{ij}^t can be calculated. To avoid zero values for p_{ij}^t, add 0.0001 uniformly to p_{ij}^t, as shown in Eq. (3):

$$p_{ij}^t = \frac{y_{ij}^t + 0.0001}{\sum_{t=1}^{T} \sum_{i=1}^{m} \left(y_{ij}^t + 0.0001 \right)} \tag{3}$$

The information entropy e_j of the indicator j can then be obtained:

$$e_j = -\frac{1}{\ln mT} \sum_{t=1}^{T} \sum_{i=1}^{m} p_{ij}^t \ln p_{ij}^t \tag{4}$$

Using the information entropy e_j, the weight w_j can be calculated:

$$\omega_j = \frac{1 - e_j}{\sum_{j=1}^{n}(1 - e_j)} \tag{5}$$

3.2.1.3. Game theory model. To avoid the one-sidedness and arbitrariness of using a single method to determine weights, this study constructs a game theory model with the Nash equilibrium as the goal, treating the weight results obtained from AHP and the global entropy method as the two parties in the game. By seeking the Nash equilibrium point of the two, the combined subjective and objective weights are calculated (Lai et al., 2015). Therefore, final weights reflect both the accuracy of objective data and the reliability of expert experience judgment.

First, perform a consistency test. The essence of the game theory combined weighting is to integrate the results of the global entropy method and AHP in the assessment of oil and gas investment risk. Therefore, before using game theory for combined weighting, the weighting results of both methods must undergo a consistency test. The consistency degree of the results from different weighting methods can be represented by a distance function:

$$d(W_1 W_2) = \left[\frac{1}{2}\sum_{j=1}^{n}(\omega_{1j} - \omega_{2j})^2\right]^{\frac{1}{2}} \tag{6}$$

where W_1 is the weight assigned by the entropy method; W_2 is the weight assigned by AHP; w_{1j} is the weight of the ith secondary investment risk indicator assigned by the entropy method; w_{2j} is the weight of the ith secondary investment risk indicator assigned by AHP; the smaller the value of $d(W_1 W_2)$, the higher the consistency between the two methods for overseas oil and gas indicator weighting results. It is considered to satisfy the consistency requirement when the value of $d(W_1 W_2)$ is less than 0.1 (Li et al., 2019).

To obtain the optimal weighting combination method, i.e., minimizing the deviations between the game theory combined weighting result vector and the single method weighting result vector, the optimal weight coefficients are solved according to the following formula:

$$\min \left\| \sum_{k=1}^{L} \beta_k \omega_k^T - \omega_k \right\|^2 (k = 1, 2) \tag{7}$$

where ω is the combined weight vector of the entropy method and AHP; ω_k^T is the weighting result of a single method k; β_k is the weight coefficient and is subject to the constraint that $\beta_k > 0$. After obtaining the optimal weight coefficient (β_1, β_2), normalize the weight coefficients:

$$\beta_k^* = \frac{\beta_k}{\sum_{k=1}^{2}\beta_k} \tag{8}$$

As a result, the comprehensive weight vector of oil and gas investment risk indicators is:

$$\omega^* = \beta_1^* \omega_1^T + \beta_2^* \omega_2^T \tag{9}$$

3.2.2. TOPSIS-GRA model to rank the investment environment risk

The TOPSIS model measures the closeness of alternatives to

positive and negative ideal solutions through Euclidean distance, while the GRA model employs grey relational coefficients to depict shape similarity between sequences. Both evaluation techniques have their merits and have been extensively applied in various domains. The comprehensive risk proximity of each resource country is weighted summation by results of TOPSOS and GRA, and the weights of different methods are based on decision-makers' preferences for location and shape. Their combination enables the assessment of alternative solutions in terms of both location and shape similarity, thus enhancing decision-making quality.

A shortcoming of the traditional TOPSIS model is its inability to accurately reflect the longitudinal changes in risk across different years due to the independence of ideal solutions (Ma and Jiang, 2022). To address this issue, this study integrates data from previous years in the selection of ideal solutions, ultimately facilitating the observation of longitudinal risk variations.

The weighted normalized matrix $\boldsymbol{C} = (Z_{ij})_{m \times n}$ is obtained by multiplying each column of the normalized matrix $\boldsymbol{B}$ representing the investment risk situation of resource countries with the corresponding game-theoretic weight ω. Here, the product of the normalized data y_{ij} and the weight ω_j^* is denoted as $Z_{ij} = y_{ij}\omega_j^*$.

Positive and negative ideal solutions Z^+ and Z^- are determined for each secondary risk indicator, as shown in Eq. (10).

$$\boldsymbol{Z}^+ = \{z_1^+, z_2^+, \cdots, z_n^+\}, \boldsymbol{Z}^- = \{z_1^-, z_2^-, \cdots, z_n^-\} \tag{10}$$

where, $z_j^+ = \max z_j^t, z_j^- = \max z_j^t (j = 1, 2, ..., n; t = 1, 2, ..., T)$.

After establishing the positive and negative ideal solutions for all indicators across years, the Euclidean distances to the positive and negative ideal solutions can be computed for each resource country using Eqs. (11) and (12):

$$d_i^+ = \sqrt{\sum_{j=1}^{n}\left(z_{ij} - z_j^+\right)^2} \tag{11}$$

$$d_i^- = \sqrt{\sum_{j=1}^{n}\left(z_{ij} - z_j^-\right)^2} \tag{12}$$

The grey relational coefficient matrices $\boldsymbol{A}^+ = \{a_{ij}^+\}_{m \times n}$ and $\boldsymbol{A}^- = \{a_{ij}^-\}_{m \times n}$, describing the relationships between each resource country and the positive and negative ideal solutions z_j^+ and z_j^-, are calculated using Eqs. (13) and (14):

$$a_{ij}^+ = \frac{\min\limits_{j}\min\limits_{i}\left|x_j^+ - x_{ij}\right| + \rho\max\limits_{j}\max\limits_{i}\left|x_j^+ - x_{ij}\right|}{\left|x_j^+ - x_{ij}\right| + \rho\max\limits_{j}\max\limits_{i}\left|x_j^+ - x_{ij}\right|} \tag{13}$$

$$a_{ij}^- = \frac{\min\limits_{j}\min\limits_{i}\left|x_j^- - x_{ij}\right| + \rho\max\limits_{j}\max\limits_{i}\left|x_j^- - x_{ij}\right|}{\left|x_j^- - x_{ij}\right| + \rho\max\limits_{j}\max\limits_{i}\left|x_j^- - x_{ij}\right|} \tag{14}$$

The distinguishing coefficient ρ, with a range of [0,1], is set to 0.5 in this study.

Grey relational degrees r_i^+ and r_i^-, reflecting the proximity of each resource country to the positive and negative ideal solutions, are determined as per Eqs. (15) and (16):

$$r_i^+ = \frac{1}{n}\sum_{j=1}^{n} a_{ij}^+ \tag{15}$$

$$r_i^- = \frac{1}{n}\sum_{j=1}^{n} a_{ij}^- \tag{16}$$

To account for the different result ranges of the TOPSIS and GRA methods, the euclidean distances and grey relational degrees are dimensionless-processed for each resource country using Eqs. (17)–(20):

$$R_i^+ = \frac{r_i^+}{\max r_i^+} \tag{17}$$

$$R_i^- = \frac{r_i^-}{\max r_i^-} \tag{18}$$

$$D_i^+ = \frac{d_i^+}{\max d_i^+} \tag{19}$$

$$D_i^- = \frac{d_i^-}{\max d_i^-} \tag{20}$$

where dimensionless-processed grey relational degrees are represented as R_i^+ and R_i^-, and dimensionless-processed Euclidean distances are represented as D_i^+ and D_i^-.

The comprehensive risk proximity of each resource country is constructed using Eqs. (21) and (22):

$$T_i^+ = \alpha_1 D_i^- + \alpha_2 R_i^+ \tag{21}$$

$$T_i^- = \alpha_1 D_i^+ + \alpha_2 R_i^- \tag{22}$$

where α_1 and α_1 indicate the decision-makers' preferences for location and shape, and $\alpha_1 + \alpha_2 = 1$. Decision-makers can set α_1 and α_1 according to their preferences. In this study, values are set as 0.5 for each. T_i^+ and T_i^- represent the proximity of the resource country to the positive and negative ideal solutions, respectively.

Finally, the relative proximity of each resource country is calculated using Eq. (23):

$$S_i = T_i^+ / \left(T_i^+ + T_i^-\right) \tag{23}$$

where S_i denotes the proximity of the sample to the positive ideal solution in terms of distance and shape. Smaller values of S_i indicate closer proximity to the positive ideal solution, implying lower oil and gas investment risk for the resource country.

3.2.3. GM (1,1) model to forecast the investment environment risk

The GM (1,1) (grey prediction model) can filter or eliminate irregular fluctuations in empirical analysis sample sequences, reflecting trend characteristics and predicting future trends. As a dynamic system of quasi-differential equations, the grey prediction model essentially accumulates original data once, generating data sequences with specific patterns. A first-order differential equation model is then constructed, yielding a fitting curve for system predictions (Gu et al., 2016).

To establish the GM (1,1) model, a level ratio test must be performed on the time series. If all level ratio values fall within $\left(e^{-\frac{2}{n+2}}, e^{\frac{2}{n+2}}\right)$, the data is suitable for model construction. If the level ratio

test is not passed, a "translation transformation" is applied to the sequence, ensuring the transformed sequence meets the level ratio test requirements. The calculation formula for λ is given in Eq. (24).

$$\lambda = \frac{x^0(k-1)}{x^0(k)}; k = 2, 3, ..., n \tag{24}$$

In this study, all level ratio values for different regional time series sequences are within the range (0.67, 1.492), indicating the original sequences are suitable for grey prediction model construction.

Before constructing the grey prediction model, the original time series data must be processed to weaken its randomness. The processed data is called a generated sequence. For an original sequence $X^{(0)}$ and a newly generated sequence $X^{(1)}$ that satisfy Eq. (25):

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i); k = 1, 2, 3, ..., n \tag{25}$$

where $X^{(0)} = (x^0(1), x^0(2), ..., x^0(n)), X^{(1)} = (x^1(1), x^1(2), ..., x^1(n))$ is known as the first-order accumulated generation, denoted as 1-AGO (Accumulating Generation Operator). Accumulated generation involves successively accumulating data from the original time series to create a new generated sequence.

The GM (1,1) model primarily constructs a differential equation model for the new generated data sequence, derives the time response function of the differential equation, performs inverse calculation using the accumulated subtraction method, and finally recovers the original data sequence to obtain the prediction model. The specific calculation steps are as follows:

First, define the grey derivative of $x^{(1)}$ as:

$$d(k) = x^{(0)}(k) = x^{(1)}(k) - x^{(1)}(k-1) \tag{26}$$

Let $z^{(1)}(k)$ be the adjacent value generation sequence of sequence $x^{(1)}$, that is:

$$z^{(1)}(k) = ax^{(1)}(k) + (1-a)x^{(1)}(k-1) \tag{27}$$

The GM (1,1) grey differential equation model is defined as Eq. (28):

$$x^{(0)}(k) + az^{(1)}(k) = b \tag{28}$$

In the above equation, $x^{(0)}$ is the grey derivative, a represents the development coefficient of the sequence's development pattern and trend, $z^{(1)}(k)$ is the whitening background value, and b is the grey action quantity reflecting the sequence's changing relationships.

Introduce vector matrix notation:

$$\boldsymbol{u} = \begin{bmatrix} a \\ b \end{bmatrix}, Y = \begin{bmatrix} x^{(0)}2 \\ x^{(0)}3 \\ ... \\ x^{(0)}n \end{bmatrix}, B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ ... & 1 \\ -z^{(1)}(n) & 1 \end{bmatrix} \tag{29}$$

Thus, the GM (1,1) model can be represented as Eq. (30):

$$Y = B\boldsymbol{u} \tag{30}$$

Using the least squares method, the estimated value of a and b can be obtained:

Table 1
Selected countries along the BRI.

Areas	Countries
Middle East	Saudi Arabia, Iran, UAE, Qatar, Iraq, Turkey, Kuwait, Oman, Lebanon, Bahrain, Yemen
Central Asia - Russia	Russia, Kazakhstan, Uzbekistan, Azerbaijan, Turkmenistan
Central and South America	Venezuela, Chile, Peru, Guyana, Trinidad and Tobago, Argentina, Uruguay, Suriname, Ecuador, Bolivia
Asia-Pacific	New Zealand, Malaysia, Indonesia, Sri Lanka, Philippines, Cambodia, Thailand, Pakistan, Mongolia, Brunei, Bangladesh, Papua New Guinea, Myanmar
Africa	Morocco, South Africa, Nigeria, Gabon, Namibia, Algeria, Madagascar, Kenya, Egypt, Ethiopia, Côte d'Ivoire, Congo (Brazzaville), Mauritania, Ghana, Cameroon, Chad, Tunisia, Angola, Liberia, Congo (Kinshasa), Tanzania, Niger, Uganda, Guinea-Bissau, Libya, Mozambique, Sudan, Senegal
Europe	Bulgaria, Romania, Italy, Poland, Czech Republic, Hungary, Croatia, Albania, Ukraine

$$\widehat{u} = \begin{bmatrix} \widehat{a} \\ \widehat{b} \end{bmatrix} = \left(B^T B \right)^{-1} B^T Y \tag{31}$$

Lastly, the whitening model is obtained:

$$\frac{dx^{(1)}(t)}{dt} + ax^{(1)}(t) = b \tag{32}$$

The solution can be derived:

$$x^{(1)}(t) = \left(x^{(0)}(1) - \frac{b}{a} \right) e^{-a(t-1)} + \frac{b}{a} \tag{33}$$

Finally, the observation prediction value is obtained as per Eq. (34):

$$\widehat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{b}{a} \right) e^{-ak} + \frac{b}{a}; k = 0, 1, \ldots\ldots, n \tag{34}$$

3.2.4. Data sources

The data sources for this study are diverse (see Table A1). Indicators measuring political factors mainly come from the ICRG reports released by the PRS Group. Economic indicators are sourced from the World Bank, Heritage Foundation, and National Bureau of Statistics. Oil and gas resource indicators come from EIA, IHS, and others. Business environment indicators are sourced from the Fraser Institute, BTI, and more. The "bilateral political relations" are obtained through expert panel scoring. Due to the large number of indicators, there are some missing values for individual countries. In this study, the median imputation method is used for data processing.

By the end of 2021, China has signed BRI cooperation documents with more than 140 countries around the world. Based on data availability and oil and gas resource potential, this study selects 76 countries as the research subjects (see Table 1).

4. Results and discussion

4.1. Oil and gas resource and political factors are the key factors of investment environment risks

The analytic hierarchy process requires experts to compare and score the risk indicators of the BRI countries' oil and gas investment environment. Considering the specificity of the petroleum industry, this study invites three oil and gas experts who have long been engaged in overseas oil and gas resource investment research to form an expert panel to score the risk indicators. After organizing and analyzing the expert evaluation opinions and discussing and adjusting with experts repeatedly, the values of each judgment matrix are less than 0.1, i.e., passing the consistency test, and then obtaining the subjective weight of the risk assessment indicator

system for the BRI countries' oil and gas investment environment.

Before using the game theory model, we first conduct a consistency test on the weights obtained by the analytic hierarchy process and the global entropy method, respectively. The distance of the weights of each indicator is 0.0857 (less than 1), which passes the consistency test, and we can proceed with the weight combination. The calculation results are shown in Fig. 4.

According to the combined weight results, oil and gas resources and political factors have the most significant impact on investment risk assessment among the primary indicators. Among the secondary indicators, besides oil and gas resources, government stability, "Belt and Road" Index, and internal conflicts have the highest proportions. The weight calculation results show that countries with a better oil and gas investment environment often have advantages such as richer resources, closer economic and trade relations with China, a more stable government, and favorable contracts.

4.2. Evolution of oil and gas investment environment risks

This study evaluates the oil and gas investment environment of 76 BRI countries using data from 2014 to 2021. The smaller the score of the resource country, the lower the risk of its oil and gas investment environment. Fig. 5 depicts the dynamic evolution of oil and gas investment environment risks. From 2014 to 2016, there was a general leftward shift, mainly due to increased investments in the oil and gas industry by countries after the BRI was proposed in 2013 and facilitated by the global economic recovery. The overall oil and gas investment environment improved. However, from 2017 to 2021, a general rightward trend emerged, indicating that the overall risk of overseas oil and gas investment environment increased during this period, mainly due to intensified geopolitical conflicts and the outbreak of the pandemic, which raised overall oil and gas investment risks. Similar results were also found by Deloitte (2021) and the PHBS Think Tank (2022).

Based on the average composite risk values from 2014 to 2021, the BRI countries' investment environment risk levels are divided into low, medium, high, and extremely high-risk levels at ratios of 15%, 35%, 35%, and 15%,[3] respectively. The spatial differences in risk levels are shown in Fig. 6. Low-risk countries are mainly located in regions with abundant oil and gas resources. Among them, leading oil and gas resource countries such as Russia, Saudi Arabia, Iran, Qatar, and the United Arab Emirates generally have extensive experience in oil and gas exploration and development

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[3] The allocation of risk levels depends on the distribution characteristics of investment risk. It is a fat-tailed distribution, which means that the probability density in the central part is higher than that at both ends, and the probability density at both ends decreases more slowly than that of a normal distribution charect. Besides, we also consider the investors' tolerance, consulting experts from Cnooc and Sinopec.
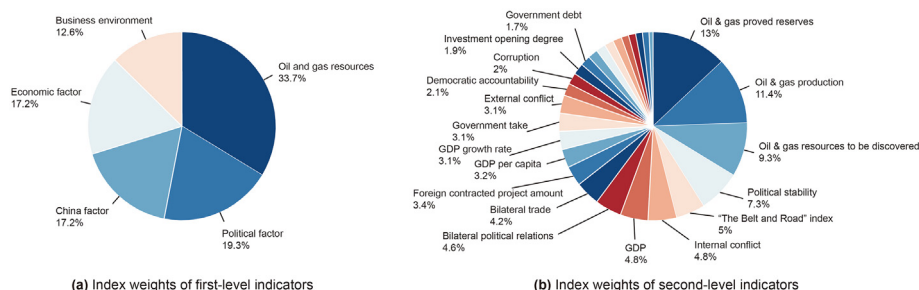
Fig. 4. Index weight value determined by game theory model (the top figure shows the weights of first-level indicators and the bottom figure shows the weights of second-level indicators).
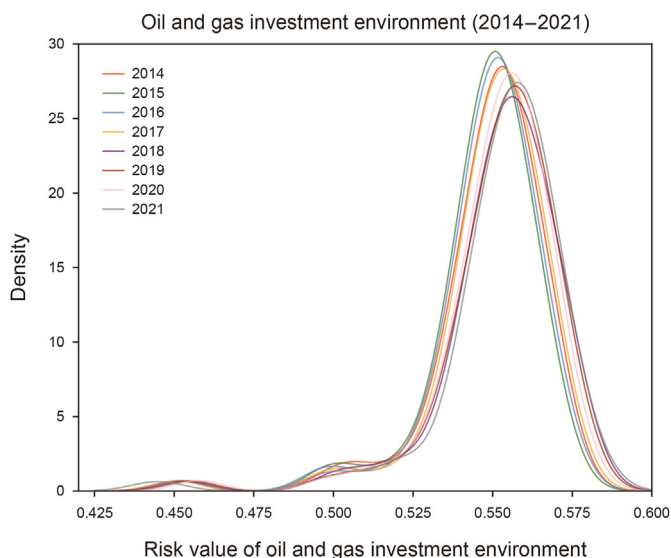

Fig. 5. Evolution of oil and gas investment environment risks in the BRI countries from 2014 to 2021.

cooperation. Extremely high-risk countries are mostly located in Africa, where exploration conditions are poor and domestic and international situations are turbulent, including Tanzania, Libya, Sudan, Guinea-Bissau, Bolivia, and Yemen.

4.3. Short-term oil and gas investment environment risk forecast

Due to the long investment cycle of oil and gas, Chinese oil companies should fully consider the future investment situation of resource countries when making overseas investments. Currently, most studies on the risk assessment of overseas oil and gas investment environments are based on cross-sectional data, and some studies only consider historical data when conducting dynamic analysis. However, in fields such as urban comprehensive carrying capacity and industrial development level, many studies have scientifically predicted the future based on historical comprehensive evaluation results (Peng et al., 2018; Jiang et al., 2021). Among them, the GM (1,1) model (grey prediction model) has the advantage of low data requirements and is more suitable for small sample prediction research (Mao and Chirwa, 2006). Therefore, this study conducts a grey prediction analysis of the oil and gas investment environment risks of BRI countries from 2022 to 2025 based on the risk assessment results of each country's oil and gas investment environment from 2014 to 2021. The results show that the ratio values of all risk value sequences are within the interval (0.982, 1.0098), indicating that the original risk value sequence is

suitable for constructing a grey prediction model. At the same time, this study uses the relative error value to verify the accuracy and fitting effect of the grey prediction. The results show that the relative error test of all resource country risk value sequences is less than 20%, indicating that the prediction model has satisfactory accuracy. The forecast results of the comprehensive oil and gas investment environment risk for each country are shown in Table 2.

To depict the short-term dynamic evolution of oil and gas investment environment risks in resource-rich countries along the BRI from 2022 to 2025, kernel density estimation is also employed to analyze the data in Table 2. This study conducts kernel density analysis on the overall oil and gas investment risk trends of 76 oil and gas resource countries from 2022 to 2025, as shown in Fig. 7. The results indicate that the overall oil and gas investment risks in the future will exhibit a trend of shifting peaks to the right and decreasing, signifying that the gap in the oil and gas investment environment among countries will widen from 2022 to 2025, with overall environmental risks increasing, mainly because of slow economic recovery and increased geopolitical uncertainty. The report from Deloitte (2021) also indicated that the increasing economic and political uncertainty enhance the risks of oil and gas investment during 14th Five Year.

Based on the forecasted comprehensive risk values for 2025, the investment environment risk levels of countries along the BRI are divided into low, medium, high, and extremely high-risk levels, with proportions of 15%, 35%, 35%, and 15%, respectively. Compared to the evaluation results from 2014 to 2021, 22 countries have experienced changes in risk levels (Fig. 8). This change also indirectly indicates that the formulation of overseas oil and gas investment decisions should consider the future risk evolution trends of resource countries.

By 2025, countries with increased risk levels are mostly characterized by political instability, intertwined tribal and religious forces, and a severe social security situation. Oil and gas investments have long cycles and significant investments; to avoid sunk costs, attention should be focused on countries with elevated risk levels to extremely high risks, including Myanmar, Uganda, Mozambique, and Senegal. Myanmar's domestic security situation remains tense, and frequent terrorist activities have led to a deteriorating oil and gas investment environment. In 2021 alone, Myanmar experienced thousands of explosions, arson, and shootings. Violence from terrorist forces in northern Mozambique's natural gas development zone has increased the short-term investment environment risks for the country. In Senegal, due to the reform of the petroleum code, oil companies' earnings have decreased, resulting in a short-term decline in the investment environment.

By 2025, countries with decreased risk levels mostly have close cooperation with China, providing a safeguard for oil companies to carry out oil and gas investments. To seize opportunities in a timely
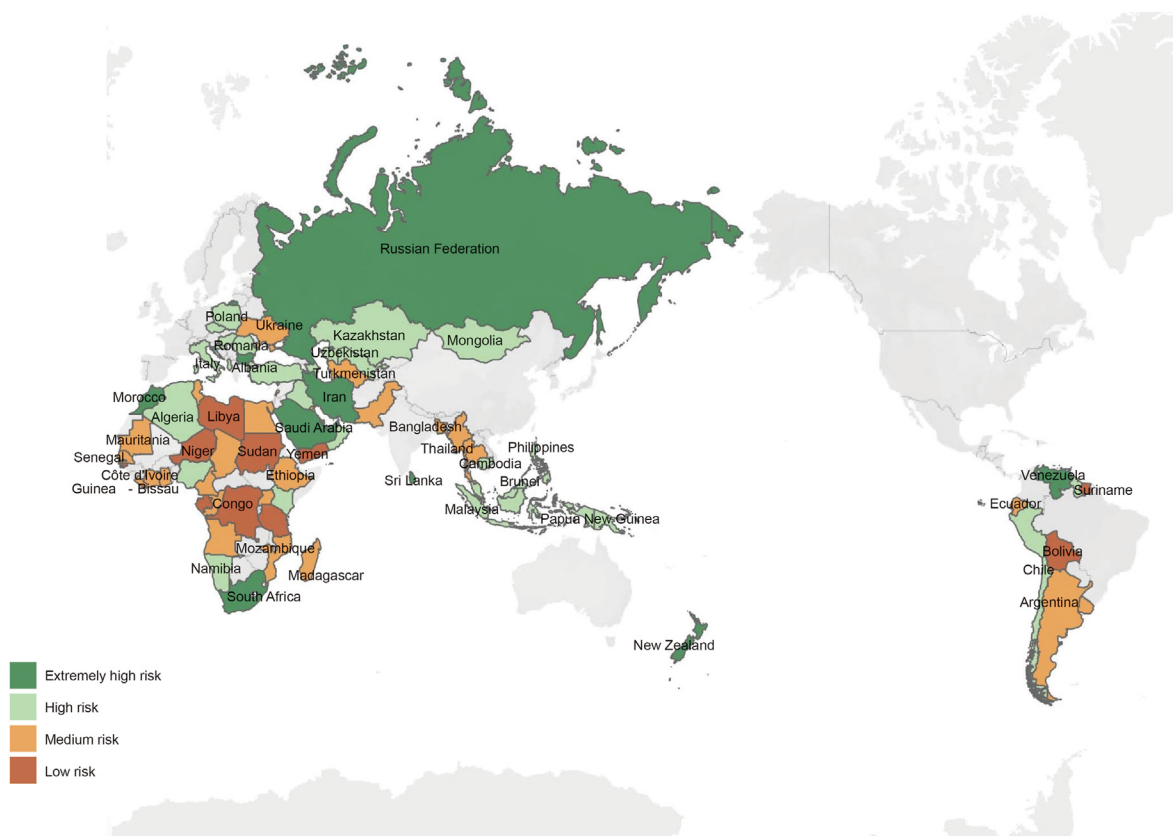
Fig. 6. Spatial differences in oil and gas investment environment risk levels of the BRI countries from 2014 to 2021.

manner, focus should be placed on countries with risk levels lowered to low risk, including Kazakhstan and Malaysia. Malaysia, as an essential node country along the Maritime Silk Road, has maintained a long-term energy cooperation relationship with China. Kazakhstan, located in Central Asia, has established a strategic partnership with China, engaging in deep cooperation in various aspects, such as politics, economy, energy, security, and culture.

4.4. Optimal resource country cluster analysis

To further assist oil companies in developing differentiated overseas investment strategies, this study identifies variations in risk characteristics among countries using the systematic clustering method and classifies low-risk countries. Systematic clustering method is a widely used method in cluster analysis, it first regards each sample as a single category, selects the pair with the smallest distance under the condition of specifying the distance between categories, merges them into a new category, calculates the distance between the new category and other categories, and then merges the two categories that are closest in distance. This way, one category will be reduced each time until all samples are merged into one category.

In this study, first, based on the comprehensive risk prediction results, we shortlist 12 low-risk resource countries with better short-term investment environments. Next, using the squared Euclidean distance between the average risk values of each country's primary indicators, we group low-risk countries with similar risk features. Combining the clustering analysis results, low-risk countries can be divided into five categories (see Table 3):

(1) Russia stands alone as the first category of low-risk countries, boasting abundant oil and gas resources and extensive

potential for Sino-Russian cooperation. Russia's oil and gas resources are plentiful, with 26 oil and gas basins mainly developed on its territory, concentrating 15.6% of the world's oil and gas resources in the Siberian region. Furthermore, Russia is keen to strengthen its collaboration with China. In 2022, the Russia-Ukraine conflict had far-reaching effects on Russia's political and economic environment. However, the sanctions accelerated Russia's eastward shift, and the divestments of western oil companies provided space for China's entry into the Russian market. Chinese President Xi Jinping's state visit to Russia from March 20 to 22, 2023, injected new momentum into the development of a comprehensive strategic partnership between China and Russia in the new era.

(2) Saudi Arabia, Iran, and Venezuela are the second category of low-risk countries, characterized by a strong willingness to cooperate with China, but with unstable domestic and foreign political situations.

Long-term geopolitical risks exist in Saudi Arabia. Firstly, since 2017, the power struggle of Crown Prince Mohammed has intensified, indirectly leading to numerous significant domestic and foreign events, such as intervention in the Yemen war in 2015, a massive anti-corruption campaign in 2017, and the arrest of former Crown Prince Nayef in 2020. It is anticipated that internal contradictions in Saudi Arabia may intensify around the time of Crown Prince Mohammed's accession, potentially causing instability. Secondly, since 2015, the Houthi rebels in Yemen have carried out "deterrence and balance actions" with Iran's support, leading to short-term increases in international crude oil prices and temporary interruptions in Saudi oil exports.

Iran and Venezuela have been repeatedly sanctioned by the

Table 2
Comprehensive risk prediction value of oil and gas investment in countries along the BRI from 2022 to 2025.

| Country	Prediction value				Country	Prediction value			
	2022	2023	2024	2025		2022	2023	2024	2025
Russia	0.4512	0.4510	0.4508	0.4506	Albania	0.5577	0.5589	0.5601	0.5613
Saudi Arabia	0.5002	0.5006	0.5010	0.5014	Trinidad and Tobago	0.5557	0.5576	0.5595	0.5614
Iran	0.5072	0.5084	0.5096	0.5108	Pakistan	0.5587	0.5599	0.5611	0.5623
Venezuela	0.5253	0.5255	0.5257	0.5260	Mongolia	0.5581	0.5596	0.5611	0.5626
UAE	0.5265	0.5273	0.5281	0.5289	Brunei	0.5598	0.5608	0.5619	0.5630
Qatar	0.5223	0.5245	0.5267	0.5290	Turkmenistan	0.5603	0.5612	0.5621	0.5630
Bulgaria	0.5390	0.5399	0.5409	0.5418	Argentina	0.5596	0.5607	0.5619	0.5631
Morocco	0.5401	0.5411	0.5421	0.5431	Ukraine	0.5612	0.5621	0.5629	0.5638
South Africa	0.5414	0.5420	0.5426	0.5432	Ethiopia	0.5597	0.5612	0.5627	0.5641
New Zealand	0.5397	0.5409	0.5422	0.5435	Uruguay	0.5605	0.5617	0.5629	0.5642
Kazakhstan	0.5438	0.5441	0.5444	0.5447	Cote d'Ivoire	0.5616	0.5627	0.5639	0.5650
Malaysia	0.5466	0.5466	0.5467	0.5467	Congo-Brazzaville	0.5618	0.5629	0.5639	0.5650
Rumania	0.5438	0.5448	0.5459	0.5470	Mauritania	0.5641	0.5648	0.5655	0.5662
Iraq	0.5457	0.5461	0.5466	0.5470	Oman	0.5615	0.5635	0.5655	0.5675
Italy	0.5453	0.5460	0.5467	0.5474	Ghana	0.5647	0.5659	0.5670	0.5682
Indonesia	0.5465	0.5474	0.5483	0.5492	Cameroon	0.5661	0.5668	0.5675	0.5682
Sri Lanka	0.5450	0.5464	0.5478	0.5492	Lebanon	0.5660	0.5668	0.5676	0.5684
Poland	0.5468	0.5479	0.5490	0.5501	Surinam	0.5686	0.5690	0.5694	0.5698
Turkey	0.5477	0.5488	0.5500	0.5511	Bangladesh	0.5663	0.5676	0.5690	0.5703
Uzbekistan	0.5474	0.5487	0.5501	0.5515	Chad	0.5675	0.5685	0.5695	0.5704
Azerbaijan	0.5512	0.5513	0.5514	0.5516	Ecuador	0.5668	0.5681	0.5694	0.5707
Czech Republic	0.5505	0.5510	0.5514	0.5519	Tunisia	0.5668	0.5683	0.5699	0.5714
Chile	0.5496	0.5507	0.5519	0.5531	Angola	0.5689	0.5697	0.5706	0.5714
Peru	0.5516	0.5524	0.5532	0.5541	Papua New Guinea	0.5641	0.5666	0.5691	0.5716
Nigeria	0.5526	0.5531	0.5536	0.5541	Liberia	0.5666	0.5684	0.5703	0.5721
Gabon	0.5597	0.5581	0.5565	0.5549	Congo-Kinshasa	0.5715	0.5725	0.5735	0.5746
Guyana	0.5528	0.5537	0.5545	0.5553	Tanzania	0.5724	0.5732	0.5740	0.5748
Philippines	0.5540	0.5549	0.5557	0.5566	Niger	0.5716	0.5728	0.5740	0.5753
Hungary	0.5544	0.5556	0.5568	0.5580	Myanmar	0.5698	0.5716	0.5735	0.5753
Namibia	0.5543	0.5557	0.5572	0.5587	Bahrain	0.5721	0.5733	0.5745	0.5756
Cambodia	0.5550	0.5563	0.5577	0.5591	Uganda	0.5719	0.5737	0.5756	0.5774
Croatia	0.5562	0.5572	0.5581	0.5591	Guinea-Bissau	0.5760	0.5769	0.5778	0.5787
Algeria	0.5566	0.5574	0.5583	0.5591	Libya	0.5761	0.5777	0.5793	0.5810
Madagascar	0.5573	0.5580	0.5586	0.5592	Mozambique	0.5741	0.5766	0.5791	0.5816
Kenya	0.5564	0.5574	0.5585	0.5595	Yemen	0.5804	0.5816	0.5828	0.5841
Kuwait	0.5589	0.5593	0.5597	0.5600	Sudan	0.5787	0.5808	0.5829	0.5850
Egypt	0.5595	0.5598	0.5601	0.5604	Senegal	0.5732	0.5774	0.5816	0.5859
Thailand	0.5584	0.5591	0.5598	0.5606	Bolivia	0.5831	0.5853	0.5875	0.5897
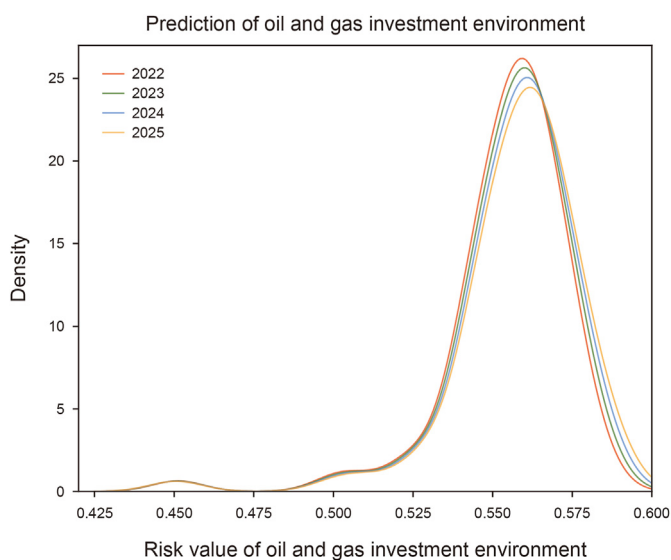
Fig. 7. Evolution trend of oil and gas investment environment risk from 2022 to 2025.

United States. Since 1979, U.S. sanctions against Iran have hindered the construction of Iranian oil and gas projects by international oil companies and impacted the development of Iran's oil and gas industry. In 2018, the United States announced its withdrawal from the Iran nuclear deal and resumed sanctions against Iran, leading Total and the China National Petroleum Corporation to withdraw from Iran's South Pars Phase 11 project. Similar to Iran's situation, since the U.S. sanctions against Venezuela began in 2016, Venezuela's crude oil production has declined dramatically, from 2.58 million barrels per day in 2016 to 635,000 barrels per day in 2021.

Despite the political turbulence in Saudi Arabia, Iran, and Venezuela, they value their cooperation with China. In 2021, China and Iran signed the "China-Iran Comprehensive Cooperation Agreement for 25 Years," representing a new phase in energy cooperation between the two countries. This agreement will help China increase its investment in Iranian natural gas export facilities. Similarly, Venezuela was among the first Latin American countries to establish a strategic partnership with China. On March 2, 2021, Venezuelan President Maduro considered reforming the oil law to allow foreign oil companies to increase ownership and management rights in oil and gas fields, attracting foreign capital and introducing a "new business model" for Venezuela's oil industry. The Saudi Arabian government's "Vision 2030″ initiative aims to prioritize ensuring China's energy security, further consolidating the comprehensive strategic partnership between China and Saudi Arabia.

(3) Qatar and the United Arab Emirates are the third category of low-risk countries, characterized by an advantageous business environment.

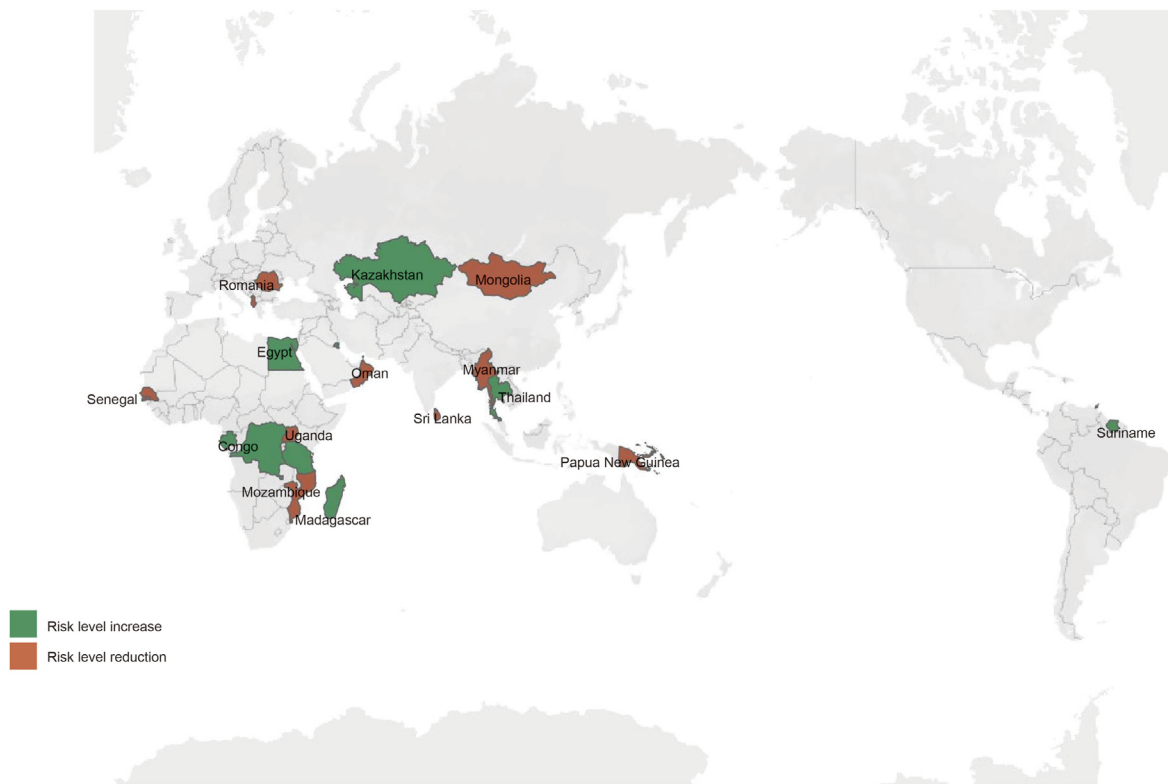**Fig. 8.** Short-term prediction of oil and gas investment environment risk level changes for countries along BRI.

Table 3
Low risk country classification.

Cluster	Characteristics	Country
Cluster 1	Rich resources, broad cooperation with China	Russia
Cluster 2	Unstable political situation, good cooperation with China	Saudi Arabia, Iran, Venezuela
Cluster 3	Stable political situation, excellent business environment	Qatar, UAE
Cluster 4	Good business environment, great potential for cooperation with China	New Zealand
Cluster 5	Balanced performances in risk factors, backward exploration and production technologies	Bulgaria, Morocco, South Africa, Kazakhstan, Malaysia

Qatar has an excellent business environment, with no history of violence against ethnic Chinese, no recent terrorist attacks, and no violent incidents targeting the oil and gas industry. Oil and gas production is the backbone of Qatar's domestic economy. Despite a deficit in 2016 due to low international oil and gas prices (Dong et al., 2020), the country has weathered the downturn thanks to its strong fiscal reserves, growing foreign exchange reserves, and numerous public investment projects and expansionary fiscal policies.

The UAE has a high per capita income, harmonious ethnic and religious relations, and no religious or ethnic conflicts. The UAE government effectively balances its interests with those of foreign companies, ensuring basic returns for contractors through tax adjustments. Foreign companies enjoy considerable autonomy and control over operations, maximizing potential or excess returns (Xia et al., 2013). In July 2018, Chinese President Xi Jinping visited the UAE at the invitation of the UAE government, resulting in cooperation agreements in finance, investment, technology, renewable energy, and the oil and gas industry, taking the friendly relationship between China and the UAE to a new level (Han et al., 2020).

(4) New Zealand is the fourth category of low-risk countries, known for its excellent business environment and great potential for cooperation with China.

New Zealand has excellent economic, political, and business environment. In November 2020, China signed the Regional Comprehensive Economic Partnership (RCEP) with the ten ASEAN countries, Japan, South Korea, Australia, and New Zealand, which will enhance the protection of China's overseas investment projects. However, between 2014 and 2019, the bilateral trade volume between China and New Zealand was relatively small due to the distance between the two countries (Feng and Wang, 2022). Compared to other low-risk countries, New Zealand's "China factor" index is average.

(5) Bulgaria, Morocco, South Africa, Kazakhstan, and Malaysia belong to the fifth category of low-risk countries.

These five countries have balanced performances in various risk factors but relatively backward oil and gas exploration and production technologies. Bulgaria has a stable political and economic environment, and favorable oil and gas contracts. Although South Africa and Morocco have not entered the top tier of African oil and gas resources, their oil and gas contracts, infrastructure construction, and overall performance are better than those of other African resource countries. Kazakhstan, as a major energy player in Central Asia, has achieved more successful oil and gas investment cooperation projects with China (Li, 2022). China has numerous patents

and world-leading technologies in the fields of oil and gas exploration, production, and deep processing, which are highly complementary to Kazakhstan's relatively less advanced industrial development. Malaysia's exploration and development technology, financial strength, and infrastructure limitations have resulted in low overall exploration levels in some oil and gas basins, leaving significant potential for further exploration.

5. Conclusions and policy recommendations

5.1. Conclusions

To mitigate the adverse effects of investment risks on overseas oil and gas projects in China, this study establishs a risk assessment index system for the oil and gas investment environment of the Belt and Road Initiative (BRI) countries, and identifies the oil and gas investment environment risks of 76 BRI countries from 2014 to 2021 by employing TOPSIS-GRA evaluation model. Lastly, utilizing the grey prediction model based on historical risk values, country-specific risk values from 2022 to 2025 are forecasted. The primary research conclusions are as follows:

(1) Significant regional heterogeneity exists in the investment environment risks of resource-rich countries. Low-risk countries are predominantly located in regions abundant in oil and gas resources, such as Russia, Saudi Arabia, Iran, Qatar, and the United Arab Emirates. Extremely high-risk countries are mostly situated in Africa, where exploration conditions are unfavorable, and domestic and international situations are unstable, including Tanzania, Libya, Sudan, Guinea-Bissau, and Bolivia.

(2) Since 2017, the overall risk of investing in BRI resource-rich countries has been on an upward trend. From 2014 to 2016, the overall oil and gas investment environment improved for the 76 oil and gas resource countries due to the global economy and the initiation of the BRI. However, since 2017, the intensification of geopolitical conflicts and the global economic recession caused by the pandemic have increased overall oil and gas investment risks.

(3) Different countries exhibit significant variations in risk characteristics. According to the systematic clustering results, Russia faces extremely high economic risks due to sanctions from Western countries. Saudi Arabia, Iran, and Venezuela have strong willingness to cooperate with China but possess considerable domestic and international political instability. Qatar and the United Arab Emirates maintain stable political environments and favorable business conditions. New Zealand enjoys an excellent business environment but has average bilateral relations with China. Bulgaria, Morocco, South Africa, Kazakhstan, and Malaysia demonstrate balanced risk factors but lag in oil and gas exploration and extraction technologies.

5.2. Policy recommendations

To formulate scientifically sound strategies for selecting target countries for overseas oil and gas investment, the following policy recommendations are based on the aforementioned research results:

First, when determining the location for oil and gas investments, consider the evolving trends of investment environment risks. In future oil and gas investments, focus on countries that consistently maintain low risk, such as Russia, Saudi Arabia, Iran, Venezuela, Qatar, United Arab Emirates, New Zealand, Morocco, South Africa, Bulgaria, Kazakhstan, and Malaysia.

Second, due to differing risk characteristics among countries, China should adopt more targeted measures when investing in overseas oil and gas. For countries under western sanctions, such as Russia, seize opportunities to enter the upstream oil and gas market; for countries with unstable domestic and international political situations, such as Saudi Arabia, Iran, and Venezuela, establish security information assessment mechanisms and improve political risk early warning systems; for countries with weak cooperation foundations, such as New Zealand, strengthen oil and gas cooperation at the national level and foster favorable international relations through oil and gas collaboration; for countries with limited exploration, such as Morocco, South Africa, Kazakhstan, Malaysia, and Bulgaria, leverage China's technical advantages and seize opportunities in international competition.

CRediT authorship contribution statement

Bao-Jun Tang: Conceptualization, Project administration, Supervision, Writing − review & editing. **Chang-Jing Ji:** Formal analysis, Supervision, Writing − original draft, Writing − review & editing. **Yu-Xian Zheng:** Formal analysis, Methodology, Software, Writing − original draft. **Kang-Ning Liu:** Data curation, Methodology, Software. **Yi-Fei Ma:** Data curation, Visualization, Writing − review & editing. **Jun-Yu Chen:** Visualization, Writing − review & editing.

Declaration of competing interest

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

Acknowledgement

Appendix

Table A1
Oil and gas investment environment risk assessment indicator system

Primary indicators	Secondary indicators	Source	Direction
Political factor	Political stability	International Country Risk Guide (ICRG)	Positive
	Internal conflict	International Country Risk Guide (ICRG)	Positive
	External conflict	International Country Risk Guide (ICRG)	Positive
	Corruption	International Country Risk Guide (ICRG)	Positive
	Democratic accountability	Worldwide Governance Indicators (WGI)	Positive

Table A1 (*continued*)

| Primary indicators	Secondary indicators	Source	Direction
Economic factor	GDP per capita	World Economic Outlook Databases (WEO)	Positive
	GDP	World Economic Outlook Databases (WEO)	Positive
	GDP growth rate	World Economic Outlook Databases (WEO)	Positive
	Inflation risk	International Country Risk Guide (ICRG)	Positive
	Exchange rate risk	International Country Risk Guide (ICRG)	Positive
	Investment opening degree	World Development Indicators (WDI)	Positive
	Debt level	World Economic Outlook Databases (WEO)	Negative
China factor	Foreign contracted project amount	China Statistical Yearbook	Positive
	Bilateral economic and trade relations	China Statistical Yearbook	Positive
	"Belt and road" index	Belt and Road Portal	Negative
	Bilateral political relations	Score by experts	Positive
Oil and gas resource	Oil and gas reserves	EIA	Positive
	Oil and gas production	EIA	Positive
	Oil and gas resources to be discovered	China National Offshore Oil Corporation	Positive
Business environment	Monopoly	IHS	Positive
	Business regulation	Fraser Institute	Positive
	Power on days	World Development Indicators (WDI)	Negative
	Environment policy	Transformation Index of the Bertelsmann Stiftung	Negative
	Law and order	International Country Risk Guide (ICRG)	Positive
	Capital and People Movement restrictions	Fraser Institute	Positive
	Government take	IHS	Positive
	Investment Profile	International Country Risk Guide (ICRG)	Positive
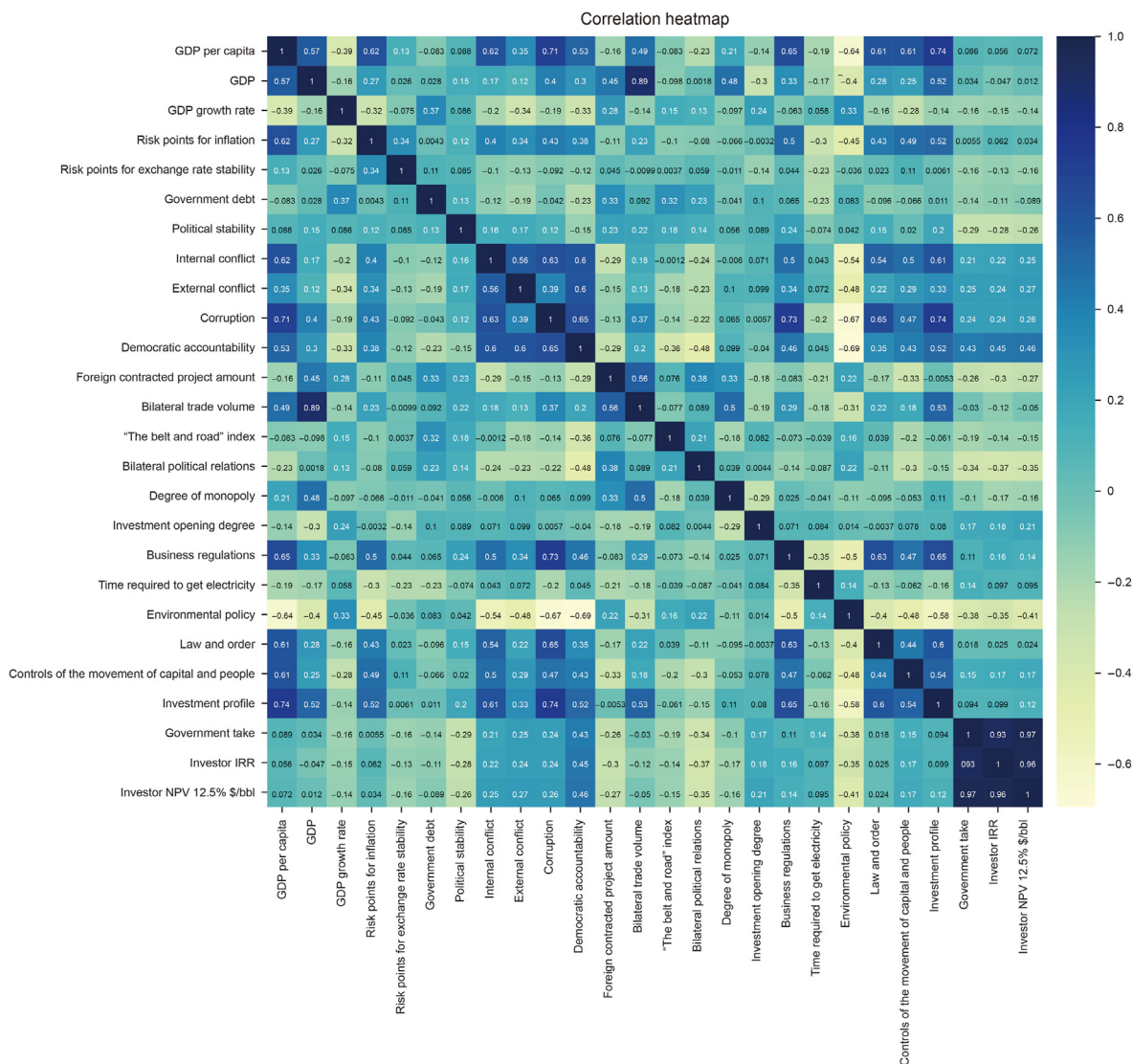
Fig. A1. Thermal diagram of the relationship between indicators

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