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Analysis of Chinese investment in renewable energy generation in Brazil

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As a result of the “Belt and Road” and “Going Global” policies, a growing number of Chinese power companies are expanding overseas, implementing global development strategies, and making investments in the overseas power industry. Several countries are undergoing an energy transition because of the rapid development of the world economy. This is being done to address the climate change issues that are a result of the overuse of fossil fuels. Brazil is also accelerating its pace of power transformation in its position as a major power generating country in Latin America. In addition to being the largest economy in South America, Brazil is also the country in which China has made the most investments. Additionally, Brazil is increasing its development efforts in wind power, photovoltaics, and other renewable energy sources in response to a large demand for renewable energy sources. Brazil’s renewable energy sector offers a great deal of potential for investment based on solid foundations for cooperation between China and Brazil. The Grey Prediction Model was used for this research to forecast Brazil’s renewable energy generation installed capacity, and the results show a positive trend in Brazil’s renewable energy generation. There is a rapid growth in wind and photovoltaic power generation over the next 5 years, with growth rates reaching 50.39% and 182.99%, respectively, suggesting that there is potential for a broad range of development. Following this, the research applies factor analysis to assess investment risks associated with Brazil’s renewable energy sector from 2000 to 2020. Based on the results of the study, Chinese power companies investing in Brazil’s renewable energy sector face the greatest political risk, while other risks gradually decrease. To avoid political risks when investing, companies should place a high priority on preventing them.

KEYWORDS

China, Brazil, renewable energy, power generation investment, investment analysis

1 Introduction

China and Brazil represent the largest emerging markets in the Eastern and Western Hemispheres, respectively. The strategic partnership between China and Brazil is celebrating its 30th anniversary this year. A meeting between President Xi Jinping and the Brazilian President Luiz Inácio Lula da Silva on 14 April 2023, emphasized the need for China and Brazil to strengthen practical cooperation, advance current major cooperation projects steadily, explore opportunities for cooperation in agriculture, energy, infrastructure construction, and strengthen cooperation in the fields of green economy, digital economy, and clean energy. In his speech, President Luiz Inácio Lula da Silva expressed his hope for increased cooperation between the two countries in a variety of areas, welcoming Chinese companies to invest in Brazil in support of digital transformation and a low-carbon development. In the future, China and Brazil are likely to collaborate extensively in the area of energy.

Since traditional fossil fuel consumption has been increasing steadily throughout the world, and non-renewable energy has been proving detrimental to climate and the environment, nations worldwide are gradually putting climate protection and sustainable energy development at the forefront of their policy agendas. Various countries are increasingly adopting renewable energy as a primary component of their energy sources transformation due to its environmental friendliness, low carbon footprint, and sustainability. As a development trend for future energy, renewable energy is being utilized to reduce carbon emissions and control climate change.

Despite the growing severity of climate issues, the Brazilian government is actively promoting renewable energy. Brazilian hydropower accounts for 60.2% of the nation's total installed capacity, making it a global powerhouse in the field of renewable energy generation (Source: Brazilian National Energy Balance (IBGE)). However, this dominance of hydroelectric power does not constitute a complete transformation of Brazil's energy infrastructure. Considering the close connection between hydroelectric power and climate change, Brazil is inadequately prepared to handle extreme weather conditions such as droughts due to its high dependence on hydroelectric power. In September 2021, Brazil experienced a drought that caused insufficient reservoir levels in hydroelectric plants, severe strain on the power supply system, and an increase in average energy prices of 6.78%, which significantly impacted people's lives (Source: China Central Television). Therefore, Brazil is simultaneously developing other renewable energy sources to mitigate the risks associated with a single method of energy generation. To facilitate the coordinated development of renewable energy sources, such as wind and solar power, the Brazilian National Electric Energy Agency has approved new regulations governing multi-energy complementation stations. By vigorously advancing construction of these stations, renewable resources can be better utilized for power generation and power stability can be improved (Zitong, 2021). In this regard, Brazil's renewable energy industry has tremendous potential for growth in the future.

Brazil is a strategic partner of China and a member of the BRICS group of countries. With Brazil being the largest economy in Latin America, it receives the most investment from China, which is Brazil's largest investment source (Fei, 2020). In Brazil, Chinese investment is primarily concentrated in the power sector. China invested $71.3 billion in Brazil between 2003 and 2019, with 45% of the investments going into the power sector (Xiaoting, 2022). Currently, China is the world's leading developer, investor, and technology provider in renewable energy. Investing in overseas renewable energy projects has become an attractive opportunity and trend for Chinese power companies as the renewable energy industry continues to expand. Electricity cooperation between China and Brazil is based on a solid foundation. A strong demand for renewable energy generation exists in Brazil, and Chinese power companies possess a wealth of experience and technology in this area. In the field of renewable energy electricity, there is great potential for cooperation between the two countries.

The renewable energy sector in Brazil offers tremendous investment potential, and investing in renewable energy is of paramount importance to Brazil's development. The application of renewable energy can mitigate the pollution caused by greenhouse gases emitted by traditional energy sources from an environmental perspective. In addition to optimizing the allocation of electricity resources, it can alleviate electricity shortages in some regions. In terms of economics, it can contribute to the transformation and upgrading of local economies, stimulate surrounding industries, and spur employment.

The political and economic situation in Brazil is complex and volatile despite the country's enormous investment potential. The existing literature focuses primarily on an overview of Chinese investment in Brazil, rather than an analysis of the risks associated with Chinese power companies operating in Brazil. Consequently, this research analyzes the future development trend of Brazil's renewable energy generation and evaluates the potential risks of Chinese power companies investing in Brazil. It summarizes the above research results to provide reference suggestions for Chinese companies interested in investing in renewable energy projects in Brazil.

2 Literature review

2.1 Economic and energy cooperation between China and Brazil

China's investment in renewable energy in Brazil has gradually developed based on the cooperation between the two countries in economic and energy fields. In 2013, China and Brazil signed a currency swap agreement to expand the operation of the financial cooperation mechanism, stabilizing the exchange rates between the two countries (Correa López, 2014). In January 2015, the first ministerial meeting of the China-CELAC Forum released the "China-Latin America and Caribbean Cooperation Plan (2015–2019)," with Latin America becoming the second largest destination for Chinese overseas investment after Asia (Fei, 2020). Studies have also analyzed the trade complementarity between China and Brazil in the energy sector, pointing out that the trade complementarity in coal between China and Brazil is gradually decreasing, while the trade complementarity in natural gas is increasing. The research suggests that due to the high pollution caused by coal combustion, China is actively seeking other alternative energy sources to mitigate climate change (Chen et al., 2021). Currently, China is gradually transitioning from a participant in global climate protection actions to a rule maker. Through diplomacy, clean energy research, and development aid, China has gained broad political support globally (Clini, 2017). Therefore, cooperation between China and Brazil in renewable energy is also an important part of China's geopolitical strategy.

In summary, China's economic and energy cooperation with Brazil has brought enormous influence to China. By establishing closer cooperation with developing countries, such as South-South cooperation (Clini, 2017) (developing countries are mostly located in the southern hemisphere and the southern part of the northern hemisphere, hence economic and technical cooperation among developing countries is called "South-South cooperation"), China is gradually becoming a leader in the global fight against climate change.

2.2 Chinese investment in the Brazilian electricity industry

As the largest economy in Latin America, Brazil is the country where China has invested the most. In addition to its abundant renewable energy resources, Brazil has a large potential for electricity generation (Pereira et al., 2012). Compared to other regions of the world, Brazil has maintained a relative advantage in the use of renewable energy in recent decades. Therefore, Brazil is also a major investment destination for several Chinese power companies, such as Three Gorges Group and State Grid (Li et al., 2020). As of 2010, China has steadily increased its investment in the Brazilian electric power industry (Li et al., 2018). After 2015, Chinese power companies shifted their investment focus from the distribution industry to the production and transmission of electricity. From 2019 onwards, Chinese business investments have shifted from the southeastern states to states in the northeast (Aguilar, 2023). The Chinese have become the largest investors in the Brazilian electricity industry as of 2019, owning about 10% of the generation sector, 12% of the transmission sector, and 12% of the distribution sector (Barbosa, 2021).

To examine the factors influencing Chinese investment in Brazil, Cai (2022) (Yijin, 2022) used a random frontier gravity model to examine 25 Latin American countries and regions, including Brazil. The study found a positive correlation between infrastructure, resource endowment, government efficiency, and investment efficiency. Investment is not significantly influenced or hindered by factors such as trade dependence or geographical distance. In terms of investment efficiency, factors such as the protection of property rights, government spending, and labor freedom are negatively correlated. From 2003 to 2018, Wang (2020) (Fei, 2020) examined the drivers of Chinese direct investment in Brazil using stepwise regression analysis. Based on the study, Chinese investment in Brazil is driven primarily by market opportunities, followed by trade opportunities, with resources not being the primary focus. Furthermore, Chinese investment in Brazil has remained relatively stable, and Brazil's economic instability or even recession does not appear to have affected Chinese investment practices.

Through the creation of an energy regulatory framework and the implementation of government incentives, Brazil has increased the attractiveness of Chinese electricity companies for investment (Zhang et al., 2011). Additionally, Brazil is promoting the development of its own solar and wind power industries by imposing specific tariffs. For instance, photovoltaic modules and wind turbines are subject to a tariff (Pathak and Shah, 2019). In the references (Adami et al., 2022; Denes_Santos and da Cunha, 2020) there are a number of recommendations for developing public policies to promote the development of wind and photovoltaic power generation industries in Brazil. Brazilian economic policies also play a bidirectional causal relationship in the development of renewable energy (Lu et al., 2021).

China's power companies are expanding their investment efforts in Brazil, and the Brazilian electricity market is also receiving increased attention. Brazil has also enacted policies designed to encourage Chinese power companies to invest in and promote its domestic renewable energy sector. However, current research tends to focus more on summarizing and organizing Chinese investments in the Brazilian power industry, as well as policies intended to attract foreign investors. The Brazilian renewable energy sector currently has limited literature on the analysis of future investment potential and investment risks.

2.3 Brazilian renewable energy development research

The issue of climate change has gained worldwide attention due to the excessive consumption of fossil fuels and the large amount of carbon dioxide released after combustion. Brazil is currently ranked as one of the seven largest carbon-emitting countries in the world (Udemba and Tosun, 2022). Research on the development of renewable energy in Brazil is therefore of great importance.

Reference (De Andrade et al., 2015) analyzes Brazil's energy structure by studying the evolution of energy use in sectors such as transportation, trade, and residential areas. It predicts the energy development trends up to 2030, indicating that the future renewable energy market is full of promise. Meanwhile, reference (Lampreia et al., 2011) argues that the development of renewable energy in Brazil in the coming decades will significantly influence Brazil's process of becoming a developed country, as renewable energy can not only contribute to low carbon emissions but can also increase economic attractiveness. According to Adebayo et al. (Adebayo et al., 2021) analyzing Brazilian data from 1990 to 2018, renewable energy consumption and technological progress can improve the quality of the environment. Additionally, renewable energy development will have a significant impact on economic and agricultural development (Pata, 2021). Based on the K-means method, Filho et al. (Filho et al., 2022) concluded that the development of renewable energy could promote the wellbeing of impoverished areas in Brazil. Magazzino (Magazzino et al., 2021) examined the relationship between Covid-19 and renewable energy consumption in Brazil and economic growth, finding that renewable energy can boost economic growth. Some scholars, however, argue that economic growth can only be promoted by developing and utilizing renewable energy on a large scale. Based on data analysis and research conducted on developing countries, Chen (Chen et al., 2020) concluded that renewable energy consumption only significantly impacts economic growth above a certain threshold.

In addition, some studies have compared the differences in the development trends of renewable energy between Brazil and other developing countries. For example, reference (Simon et al., 2018) compared and analyzed the differences in the development paths of renewable energy transformation between Brazil and Mexico. The two countries have completely different endowments of renewable resources. Brazil has abundant hydroelectric and biomass resources, and also has high wind and photovoltaic power generation potential, so it tends to promote energy transformation through these resources. According to Mexico's renewable energy potential, it needs to achieve energy transformation through the promotion of geothermal power generation, wind power, photovoltaic power generation, and other methods.

The development of renewable energy is also directly related to the reform of the electricity market. Bradshaw (Bradshaw, 2018) summarized the trading varieties and trading mechanisms of high-proportion renewable energy participation in the electricity market in Brazil and emphasized the benefits of energy auctions for wind and solar energy as well as net metering regulations for non-hydropower renewables.

Currently, solar energy is considered the most promising renewable energy in Brazil (de Sousa Stilpen and Cheng, 2015). Brazil's photovoltaic industry has the strongest growth momentum, making it the fastest-growing renewable energy in Brazil (Rigo et al., 2022). Using big data processing, Reference (Costa et al., 2023) conducted a study on the future development trends of photovoltaic (PV) power generation in Brazil, concluding that PV power generation in Brazil will grow linearly in the coming months. As Brazil has numerous artificial reservoirs, Silva (Silva et al., 2023) believes that floating solar power generation will have great potential in the future. However, solar energy development also faces obstacles. Renewable energy development in Brazil is limited by underdeveloped related industries and weak transmission infrastructure (Frate and Brannstrom, 2017). Additionally, the large area required for photovoltaic (PV) power generation compared to traditional forms of generation as well as the higher cost of purchasing land further constrain its development (Shah et al., 2015).

In addition to its underdeveloped wind power industry, Brazil also depends on imported core materials and components to develop its wind power industry. Consequently, materials such as wind turbines are heavily reliant on imports, which results in high initial costs (Diógenes et al., 2020). As technology advances, however, PV and wind power generation equipment costs have decreased in recent years, and future generation costs are expected to decrease as well (de Andrade Santos et al., 2020). As a whole, wind and solar power have been supported in a few policies, such as the National Policy on Climate Change (PNMC) and the Nationally Determined Contribution (NDC) (Costa et al., 2022). Therefore, Brazil's future renewable energy sector has a significant development potential.

The current research on the development of renewable energy in Brazil is primarily focused on how renewable energy affects economic growth and how reforms to the electricity market advance the development of renewable energy. Due to differences in resource endowments, the path to achieving renewable energy transformation varies from country to country. Currently, photovoltaic power generation is considered to have the most development potential in Brazil, there are also some factors that limit its development. There is, however, little literature regarding how foreign power companies' investments affect the development of renewable energy in Brazil.

2.4 Research on predicting installed capacity of power generators

Currently, installed capacity prediction for power generators is primarily based on time series analysis and machine learning.

Typically, scholars use a grey prediction model or optimize it to predict the installed capacity of power generators. Gu (2021) (Yu, 2021) applied the gray prediction model to forecast renewable energy installed capacity and generation in China over the next 10 years. A verification of the model's accuracy was performed, and the results showed that the grey prediction model had a high level of accuracy with an average error of only 1.11%. Using the gray prediction model and particle swarm algorithm, Dong (2022) (Yulin, 2021) predicted the generation capacity of wind power in China based on the grey prediction model. Compared to the original model's predictions, the optimized model provided more accurate results. Based on the nonhomogeneous data of photovoltaic power generation installed capacity in China, Shu (2022) (Fuhua, 2022) optimized the traditional grey prediction model to provide an unbiased GM (1,1, K) model. Using this model, the installed capacity of photovoltaic energy generation was predicted, and the results indicated that the prediction was accurate. Wang (2017) (Ma et al., 2017) used the grey prediction model to forecast the actual capacity of a 100 MW large-capacity generator unit and analyzed the error. To forecast power consumption, (Guefano et al., 2021) combined the grey model with the vector autoregressive model.

Regarding the prediction of generator installed capacity through machine learning, (Song et al., 2018) proposed a neural network system model for predicting the installed capacity of distributed photovoltaics for the target year using machine learning, providing a novel approach to long-term load forecasting for grid-connected distributed photovoltaic power plants. Using Extreme Learning Machine (ELM), an artificial neural network model, (Rocha et al., 2018) developed a computational tool for parameter selection based on particle swarm optimization for ELM to estimate daily power generation in micro-generator systems. In 2024, Qiu (Shuqi et al., 2024) proposed a method for predicting photovoltaic power generation using Stacking ensemble learning. Compared to other methods, this algorithm had smaller errors.

In Brazil, however, the sample size of renewable energy generation-related data is small, making it unsuitable for machine learning algorithms. For this reason, the grey prediction model was chosen for the purpose of forecasting.

2.5 Electricity investment risk research

Reference (Ahmadi et al., 2021) constructs an investment portfolio simulation model to analyze investment risks in the Iranian electricity industry, highlighting the benefits of diversifying investment portfolios in reducing investment risks. Using a cross-classified multilevel model, Reference (Breitschopf and Alexander-Haw, 2022) assesses the financing cost risk of renewable energy from the perspective of electricity auctions, concluding that the implementation of auctions will not increase financing costs. A machine learning prediction model was used by Reference (Đukanović et al., 2023) to predict electricity debt risk in Montenegro, suggesting that low-income countries may be at greater risk of default.

Regarding policy, reference (Petrovich et al., 2021) evaluates household solar power generation from the perspective of policy risk and market risk, emphasizing that the industry is more susceptible to policy risks. Compared to policies in the wind energy industry in different countries, Reference (Pathak and Shah, 2019) suggests that wind power development can be enhanced if policies favorable to

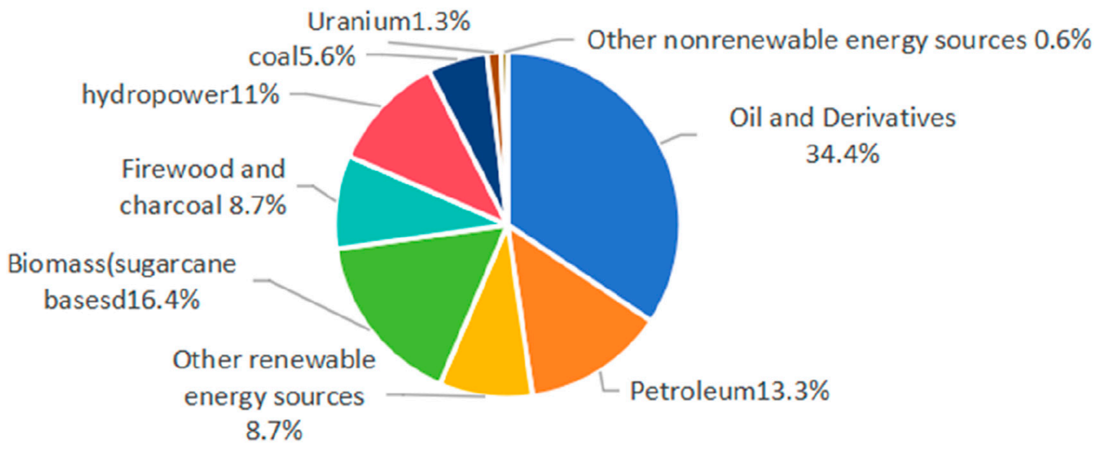

FIGURE 1
2021 Primary energy supply structure in Brazil. Source: (IBGE) https://www.ibge.gov.br/en/home-eng.html.

wind power generation are implemented, such as feed-in tariffs, economic stimuli, fiscal subsidies, and renewable energy portfolio standards.

Reference (Farfan and Breyer, 2017) constructs sustainable development indicators at the national level of the power industry to assess investment risks. To assess investment risks, Reference (Brown et al., 2015) constructs a risk assessment model consisting of four primary dimensions, namely, governance, economy, operation, and society, and 70 subdimensions. Based on the assessment of investment risks in various countries along the Belt and Road, Reference (Yuan et al., 2018) provides a nine-dimensional risk evaluation indicator system and provides recommendations.

The majority of investment risk research is based on analytical methods, with some scholars using Analytic Hierarchy Process (AHP), Fuzzy Comprehensive Evaluation, and Entropy Weight Method to analyze investment risks in a comprehensive manner. However, these methods are typically qualitative and rely on experts to score, which may lead to bias in the results of the analysis. As a result, this study employs Factor Analysis to quantitatively evaluate risks by querying data from institutions such as ICRG, WDI, and IBRD, which helps to make the analysis results more objective.

3 Brazil's renewable resource endowment and current development status

3.1 Brazil's current energy structure

The largest country in South America, Brazil is located in the northern part of the continent. Additionally, Brazil has the highest GDP in South America, ranking 13th globally in 2021. With 62.6% of the country's primary energy supply coming from fossil fuels, fossil fuels represent the majority of the country's primary energy source. With 34.4% of these fossil fuels coming from petroleum and its derivatives, petroleum holds a significant share. It is due to the high reliance on fossil fuels that Brazil is compelled to undergo an energy transition. According to Figure 1, biomass, primarily derived from sugarcane, accounts for the largest share of renewable energy sources at 16.4%. As the first nation globally to sustainably utilize biofuels and leading the world in biofuel utilization, Brazil has advanced technology in biomass energy (Guoqing, 2021). With oil and gas accounting for 50% of Brazil's primary energy supply, the country still relies primarily on fossil fuels for its primary energy supply. An energy transition is therefore necessary.

3.2 Renewable resource endowment in Brazil

As a major hydroelectric power nation worldwide, Brazil has an abundance of renewable energy resources. A large portion of the country's hydroelectric resources are concentrated in the northern Amazon River basin, with the resources in the north being more abundant than in the south. According to statistics from the International Renewable Energy Agency (IRENA), Brazil's total installed capacity of hydroelectric generators reached 109,426 MW in 2021. Brazil ranked second in the world in hydroelectric power generation in 2018, with 389 TW-hours (TWh). In addition to hydroelectric power, Brazil has considerable potential for renewable energy sources such as wind, solar, and biomass (Figure 2, Figure 3). Compared to other countries, Brazil has a greater potential for wind, solar, and biomass energy development. Wind energy resources are primarily concentrated in the eastern and southern regions of the country, with a total installed capacity of 21,161MW, an average wind speed of 7.02 m per second, and an average power density of 326 W per square meter. It is estimated that wind power generation accounts for only 11.4% of all electricity generated, indicating considerable potential for future growth. As for solar energy, Brazil's solar resources are primarily concentrated in the Brazilian Highlands in the east. The national average photovoltaic (PV) output power stands at 4.27 kWh/kWp. PV generators produce 6,665 GWh of electricity at a total installed capacity of 7,879 MW. A relatively low level of development and substantial untapped potential for further development are evident from this account for only 2.6% of total national electricity generation. In the realm of biomass energy, Brazil similarly possesses excellent

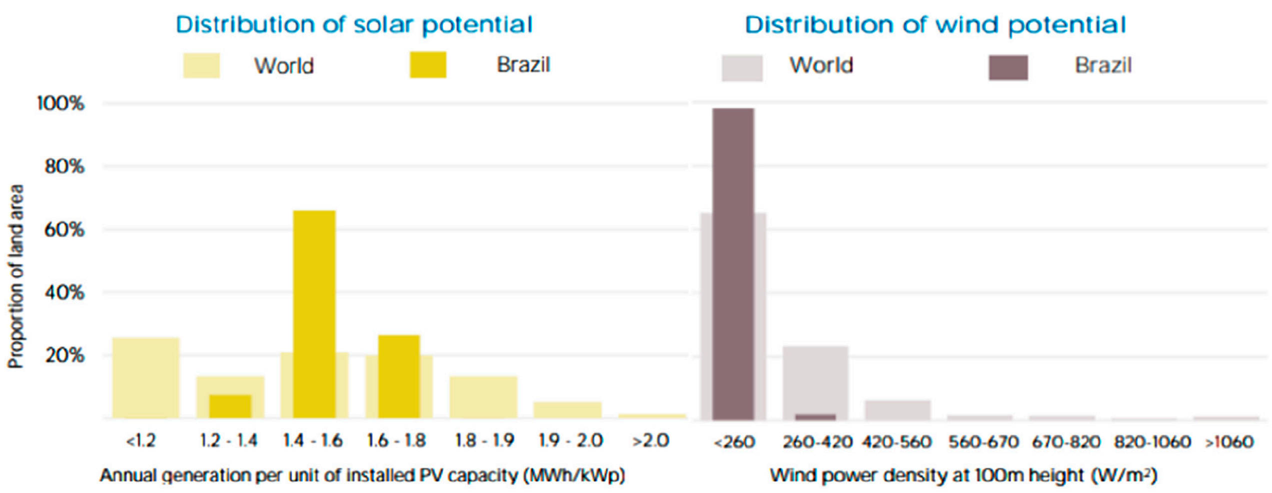

FIGURE 2
Wind energy resource and solar energy resource potential in Brazil. Source: International Renewable Energy Agency https://www.irena.org/.

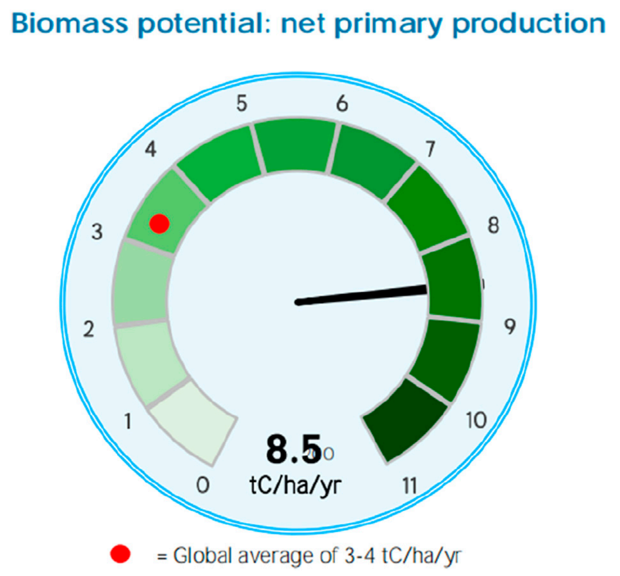

FIGURE 3
Biomass energy potential in Brazil. Source: International Renewable Energy Agency https://www.irena.org/.

natural resource endowments. Biomass energy generation nationwide stands at 16,300 megawatts. Biomass energy in Brazil is primarily generated from sugarcane. To promote the development of biomass energy generation, Brazil enacted the "National Biofuels Policy" in 2017. By 2020, sugarcane-based electricity accounted for 82% of national biomass energy generation. According to the Brazilian Sugarcane Industry Association, Brazil's biomass energy production will grow by at least 55% by 2030. Overall, Brazil is endowed with an exceptional resource endowment, with wind, solar, and biomass energy generation potentials exceeding those of the rest of the world. There is substantial room for future growth in these resources, which have not been fully exploited.

4 Current status of renewable energy electricity generation in Brazil

Renewable energy has played a significant role in the development of Brazil's electric power industry. The Brazilian Energy Research Company reports that in 2018, Brazil ranked third globally in terms of installed capacity for renewable energy electricity generation, behind only China and the United States. The hydroelectric power sector dominates Brazil's power supply landscape with 60.2% (see Figure 4). The majority of Brazil's hydroelectric stations are located in the Amazon River Basin, which has a tropical rainforest climate and abundant water supplies. With an average flow rate of 219,000 cubic meters per second, the Amazon River has the highest flow rate in the world, equivalent to seven Yangtze Rivers. Taking advantage of this abundant water supply, Brazil has access to significant hydroelectric resources.

However, in recent years, Brazil has also vigorously developed wind and solar energy sources. It is estimated that wind power capacity will account for 53% of the nation's total newly installed capacity in 2021, with wind power generation expected to increase by 27% from last year.

According to the International Renewable Energy Agency's "Renewable Energy Statistics 2021"(Table 1), Brazil's renewable energy generation increased by 57,090 GW-hours (GWh) from 2011 to 2020. The most significant increase in installed capacity was seen in wind power, which reached 54,346 GWh. Energy generated from biomass ranked second, increasing by 23,980 GWh, while solar energy exhibited the fastest growth rate, surging over a thousand times in a decade, demonstrating robust growth.

There was, however, a slight decline in the generation of hydroelectric power. This decline can be attributed to Brazil's dependence on a single energy source, mainly hydroelectric power. Due to the highly unpredictable nature of this source, electricity generation is subject to considerable fluctuations and instability. Brazil is therefore actively promoting the development

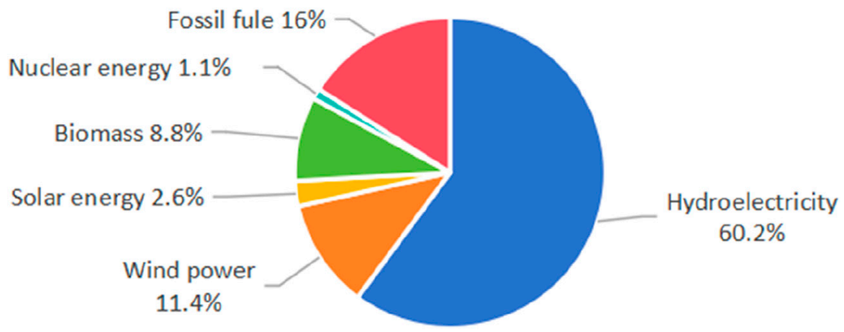

FIGURE 4
Energy generation structure of Brazil in 2021. Source: (IBGE) https://www.ibge.gov.br/en/home-eng.html.

TABLE 1 Brazilian renewable energy generation.

Year	Generation capacity (GWh)				
	Hydroelectricity	Wind power	Solar	Biomass	Total
2011	428,333	2,705	1	31,633	462,672
2012	415,342	5,050	2	34,662	455,056
2013	390,992	6,578	5	39,679	437,254
2014	373,439	12,210	17	44,987	430,653
2015	359,743	21,626	64	47,394	428,827
2016	380,911	33,489	88	49,236	463,724
2017	370,906	42,373	837	49,385	463,501
2018	388,971	48,475	3,472	51,876	492,794
2019	397,877	55,986	6,665	52,111	512,639
2020	396,381	57,051	10,717	55,613	519,762
Increment (GWh)	−31,952	54,346	10,716	23,980	57,090

Source: the Brazilia n Energy Research Company (EPE) and 《Renewable Energy Statistics 2022》.

of other renewable energy sources in order to mitigate the risks associated with the over-reliance on a single source of energy.

5 Forecast of Brazil's renewable energy generation installed capacity

The renewable energy sector in Brazil is experiencing rapid growth, providing investors with a variety of investment opportunities. In this study, historical data is combined with the Grey Prediction Model (GM) to forecast Brazil's renewable energy generation capacity, as well as analyze the potential growth of the industry. In grey theory, the GM (1,1) is the most widely used model because it determines the regularity of system changes by accumulating and deducting data, thereby predicting the future direction of things. GM is characterized by low dependence on data richness, high predictability, and good ability to predict time series data. In general, data on generator installed capacity is provided with a 1-year interval, with each data point representing the installed capacity of a certain type of energy source during that year. Due to its small sample size, nonlinearity, as well as its ability to fluctuate randomly (Yu, 2021), this data is suitable for prediction by the Grey Prediction Model.

The specific calculation principle of the Grey Prediction Model is as follows:

Define a sequence $X^{(0)} = (x^{(0)}(1), x^{(0)}(2), ..., x^{(0)}(n))$, where $x^{(0)}(k) \geq 0, k = 1.2...., n$; $X^{(1)}$ is the first order accumulated generating sequence of $X^{(0)}$:

$$X^{(1)} = \left(x^{(0)}(1), x^{(0)}(2), ..., x^{(0)}(n)\right)$$

Where $x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i)$, $k = 1.2...., n$,

$$x^{(0)}(k) + a\,x^{(1)}(k) = b$$

This is the original form of the GM (1,1) model.

Assuming $x^{(1)}$ satisfies the first-order differential equation:

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

The constants a and b are determined by the least squares estimation formula.

TABLE 2 Gray prediction model fitting results.

Energy type	Year	Actual values	Predictive value	Relative error%
Renewable energy installed capacity (MV)	2013	99,835	99,835	0
	2014	106,446	106,586	0.13
	2015	112,641	113,223	0.52
	2016	121,374	120,273	0.91
	2017	128,417	127,763	0.51
	2018	136,579	135,719	0.63
	2019	144,575	144,170	0.28
	2020	150,493	153,148	1.76
	2021	161,136	162,684	0.96
	2022	175,262	172,815	1.4
Wind power installed capacity (MV)	2013	2,202	2,202	0
	2014	4,888	5,822	19.11
	2015	7,633	7,633	0
	2016	10,129	9,554	5.68
	2017	12,304	11,590	5.8
	2018	14,843	13,750	7.37
	2019	15,438	16,040	3.9
	2020	17,198	18,468	7.39
	2021	21,161	21,043	0.56
	2022	24,163	23,774	1.61
Hydropower installed capacity (MV)	2013	86,019	86019	0
	2014	89,194	91,528	2.62
	2015	91,651	94,043	2.61
	2016	96,930	96,626	0.31
	2017	100,333	99,281	1.05
	2018	104,482	102,009	2.37
	2019	109,143	104,811	3.97
	2020	109,318	107,691	1.49
	2021	109,426	110,649	1.12
	2022	109,814	113,689	3.53
Biomass power generation installed capacity (MV)	2013	11,602	11,602	0
	2014	12,343	12,816	3.83
	2015	13,312	13,286	0.19
	2016	14,187	13,775	2.91
	2017	14,574	14,281	2.01
	2018	14,819	14,805	0.09
	2019	15,358	15,349	0.06
	2020	15,686	15,913	1.45

(Continued on following page)

TABLE 2 (*Continued*) Gray prediction model fitting results.

Energy type	Year	Actual values	Predictive value	Relative error%
	2021	16,351	16,498	0.9
	2022	17,206	17,104	0.59
Solar power generation installed capacity (MV)	2018	2,435	2,435	0
	2019	4,635	3,416.68	26.29
	2020	8,291	8,810	6.26
	2021	14,197	15,261	7.50
	2022	24,079	22,978	4.57

Source: the Brazilian Energy Research Company (EPE) and 《Renewable Energy Statistics 2022》.

$$\hat{a} = \left(B^T, B\right)^{-1} B^T Y$$

Where Y and B respectively represent

$$Y = \left[x^{(0)}(2), x^{(0)}(3), \ldots, x^{(0)}(n)\right]^T$$

$$B = \begin{bmatrix} -\frac{1}{2}\left(x^{(1)}(2) + x^{(1)}(1)\right) & 1 \\ \cdots & \cdots \\ -\frac{1}{2}\left(x^{(1)}(k) + x^{(1)}(K-1)\right) & 1 \end{bmatrix}$$

The response equation of the mean GM (1,1) model is obtained as:

$$\hat{x}^{(1)}(k) = \left(x^{(0)}(1) - \frac{b}{a}\right)e^{-a(k-1)} + \frac{b}{a}, k = 1.2...., n$$

Finally, the restored form of the original sequence is obtained as:

$$\hat{x}^{(1)}(k) = \left(1 - e^{a}\right)\left(x^{(0)}(1) - \frac{b}{a}\right)e^{-a(k-1)}, k = 1.2...., n$$

5.1 Model verification

Verifying the model is crucial before conducting forecasts of installed capacity. The purpose of this study was to collect data regarding the generation capacity of renewable energy in Brazil from 2013 to 2022. By using the Grey Forecasting Model, historical real installed capacity values were compared to predicted values (Table 2). By analyzing comparative data of the model's predicted relative errors, the effectiveness of the model is evaluated. Fitting errors within twenty percent are generally considered indicative of accurate predictions (Julong, 2002). Since photovoltaic generator capacity in Brazil is limited before 2018, the analysis begins in that year.

Based on the analysis of the fitting results, it can be seen that for most years, the actual values of electricity generation are close to those predicted, with fitting errors controlled within twenty percent in most cases. This indicates that the model's predictions are relatively accurate, thereby validating its effectiveness. For predicting the installed capacity of renewable energy generation in Brazil, it would be appropriate to use the Grey Forecasting Model.

5.2 Analysis of forecast results

In Table 3, the forecast results include the development coefficient 'a' indicating the series' trend and development pattern, the Grey action quantity 'b' expressing the series' variation relationship, and the posterior error ratio 'c' that indicates the model's accuracy. It is generally accepted that a posterior error ratio of 'c' of less than 0.5 indicates acceptable model accuracy, while a posterior error ratio of less than 0.35 indicates high model accuracy. Table 3 shows that all predicted results have a posterior error ratio 'c' less than 0.35, indicating that the model has high predictive accuracy. As a result, these forecasts should produce reasonably accurate results.

From 2023 to 2027, Brazil's total installed capacity of renewable energy generators is expected to increase by 27.33%, or 50,176 MW, indicating an enormous potential for the renewable energy industry in Brazil. The photovoltaic (PV) electricity industry has experienced the most significant growth, reaching an annual growth rate of 182.99%. In recent years, Brazil's PV, industry has experienced rapid growth, with PV, electricity increasing by a total of 10,716 GWh, from 2011 to 2020, exceeding a thousand-fold increase. Forecasts indicate that PV, electricity is expected to grow at the fastest rate, aligning with the actual situation and serving as a valuable reference point.

With a growth rate of 50.39%, wind power generation has the second-highest installed capacity growth rate. Wind resources are also abundant in Brazil, indicating a promising future for wind power production. Biomass and hydroelectric power generation, however, have experienced lower growth rates than the average. Possibly, this can be attributed to Brazil's mature hydroelectric power industry, where the majority of the country's electricity is generated by hydroelectric power. Moreover, due to the heavy dependence on hydroelectricity in Brazil, which is vulnerable to weather changes, recent efforts are being made to promote other renewable energy sources in an effort to minimize the risks associated with an overdependence on hydropower. As a result, hydroelectricity is growing at a relatively slow pace.

Considering the projected installed capacity of renewable energy generation in Brazil, it appears that the industry has tremendous potential for growth. It is anticipated that investments in these sectors will provide substantial returns.

TABLE 3 Results of the forecast of installed renewable energy capacity.

Year	Forecast of installed capacity (MV)				
	Renewable energy	Hydro electricity	Wind power	Solar	Biomass
2023	183,576	116,813	26,669	32208	17,733
2024	195,007	120,022	29,739	43249	18,384
2025	207,150	123,319	32,995	56455	19,060
2026	220,050	126,707	36,447	72252	19,760
2027	233,752	130,188	40,108	91147	20,486
Increment (MV)	50,176	13,375	13,439	58939	2,753
Growth rate%	27.33	11.45	50.39	182.99	15.52
Development coefficient a	−0.06	−0.027	−0.059	−0.179	−0.036
Grey action quantity b	97368.055	87961.909	27568.208	20357.876	12167.043
Posterior error ratio c	0.003	0.074	0.012	0.013	0.02

TABLE 4 Renewable energy investment risk evaluation indicator system.

Primary indicators	Secondary indicators	Source
Political risks	Government Effectiveness (U6)	WGI
	Control of Corruption (U7)	WGI
	Regulatory Quality (U8)	WGI
	Political Stability (U9)	WGI
	Voice and Accountability (U10)	WGI
Economic Risks	Value added by industry (U1)	Word bank
	GDP(U2)	Word bank
	Net national income (U3)	Word bank
	GDP *per capita* (U4)	Word bank
	Total reserves (U5)	Word bank
Industry risks	Renewable energy consumption (percentage of total energy consumption) (U11)	Word bank
	Electricity supply as a percentage of population (U12)	Word bank
	Length of transmission lines (U13)	EPE
	Renewable energy generation (U14)	EPE
	Per capita electricity consumption (U15)	EPE
Business environment risks	Total number of domestic listed companies (U16)	Word bank
	Total market capitalization of domestic listed companies (U17)	Word bank
	Amount of energy investment with non-state participation (U18)	Word bank
	Rule of Law(U19)	WGI

WGI:Worldwide Governance Indicators; EPE:Brazil's Energy Research Company.

6 Analysis of investment risks in Brazil's renewable energy sector

Compared with domestic investments, overseas investments often present greater risks for Chinese power companies. Therefore, this chapter analyzes Chinese investments in Brazil and constructs an investment risk evaluation index system for the Brazilian renewable energy sector to assess investment risk.

TABLE 5 Factor extraction results.

Factor	Initial eigenvalue			Extract the sum of the squares of the loads			Rotational load sum of squares		
	Eigenvalue	Variance contribution%	Cumulative variance contribution%	Eigenvalue	Variance contribution%	Cumulative variance contribution%	Eigenvalue	Variance contribution%	Cumulative variance contribution%
1	10.58	55.683	55.683	10.58	55.683	55.683	8.272	43.536	43.536
2	4.006	21.082	76.765	4.006	21.082	76.765	5.89	31.001	74.536
3	1.379	7.256	84.021	1.379	7.256	84.021	1.565	8.238	82.774
4	1.263	6.648	90.669	1.263	6.648	90.669	1.5	7.895	90.669

6.1 China's investment status in Brazil's power industry

In Brazil, Chinese power companies invest primarily in the renewable energy sector, accounting for 97% of their investments. Among them, hydropower, and wind power account for 71% and 17%, respectively, of the total installed capacity of Chinese power companies in Brazil (see Figure 5). For Chinese investors in the Brazilian energy sector, renewable energy has become a critical area.

6.2 Analysis of investment risks in Brazil's renewable energy electricity sector

6.2.1 Establishment of indicator system and data preprocessing

Power sector investments require considerable capital, involve multiple stages, and have a long investment cycle. Therefore, traditional risk assessment indicators based on economic fundamentals, financial trade, and political circumstances are not effective in evaluating Chinese power companies' overseas investments. The sector of renewable energy generation requires a specific risk assessment indicator system.

Principles for selecting investment risk indicators:

(1) Broad coverage: The basis for constructing a risk assessment indicator system should include a full and comprehensive analysis of key factors that affect investment returns.
(2) Representativeness: The inclusion of an excessive number of unrelated indicators not only complicates the model and increases computational difficulty but also amplifies the model's error by incorporating irrelevant variables, thereby diminishing the objectivity of the results.
(3) Data availability: Given the numerous factors influencing investment risks in the power sector, it is crucial to ensure the completeness and accuracy of data for each indicator within the risk assessment indicator system. This approach ensures the availability of data and its alignment with the requirements of the evaluation model.

Drawing on the aforementioned principles, this study enhances the evaluation of investment risks in the power sector, specifically targeting the renewable energy domain. By examining risk factors listed in the International Country Risk Guide (ICRG) and the Worldwide Governance Indicators (WGI) and integrating historical data from entities like the Brazilian Energy Research Company (EPE) and the World Bank, this paper constructs an indicator framework tailored to analyzing investments in renewable energy generation in Brazil (Table 4).

Firstly, it is imperative to consider political risk, which serves as an indicator of a nation's political stability, the level of corruption, and governance efficacy. For Chinese enterprises, a stable governmental environment in the host country is crucial for ensuring that government policies are both effective and consistent, thereby mitigating risks associated with project delays or deviations from planned outcomes due to economic instability and policy shifts. In this context, the Worldwide Governance Indicators (WGI) provide useful benchmarks, encompassing five

TABLE 6 Score coefficient matrix.

Indicators	Factor			
	1	2	3	4
Value added by industry	0.149	0.043	−0.148	0.03
GDP	0.133	0.007	−0.085	−0.036
Net national income	0.132	0.004	−0.083	−0.044
GDP *per capita*	0.14	0.019	−0.112	−0.018
Total reserves	0.083	−0.046	0.072	−0.092
Government Effectiveness	0.056	0.168	0.086	−0.099
Control of Corruption	0.051	0.19	−0.089	0.166
Regulatory Quality	0.072	0.217	0.196	−0.026
Political Stability	0.03	0.152	0.041	−0.082
Voice and Accountability	0.073	−0.079	−0.716	−0.06
Renewable energy consumption	−0.056	0.009	0.023	0.619
Electricity supply as a percentage of population	0.066	−0.078	−0.026	−0.013
Length of transmission lines	0.01	−0.11	0.207	−0.148
Renewable energy generation	0.031	−0.041	0.219	0.053
Per capita electricity consumption	0.071	−0.079	0.067	−0.17
Total number of domestic listed companies	−0.008	0.145	0.1	0.019
Total market capitalization of domestic listed companies	0.084	0.08	0.007	0.386
Amount of energy investment with non-state participation	0.109	0.157	0.076	0.27
Rule of Law	0.141	0.076	0.021	−0.153

sub-indicators: government effectiveness, corruption control, regulatory quality, political stability, and voice and accountability.

Secondly, it is imperative to consider economic risks in the host country, as financial conditions are intrinsically linked to investment risks. A host country underpinned by a robust financial foundation generally features stable exchange rates and low inflation, enhancing its suitability for high-return investments. Economic risks are encapsulated in five key indicators: industrial value added, GDP, national net income, GDP *per capita*, and total reserves. Industrial value-added serves as a measure of the country's industrial growth rate, with rapid industrial development suggesting strong societal demand. GDP, national net income, and GDP *per capita* provide insights into the country's economic strength and offer investors a comprehensive profile of the nation. Total reserves indicate the country's ability to repay debt, with higher reserves suggesting a lower likelihood of debt crises or bankruptcy, thereby mitigating potential investment losses for businesses.

In addition, it is essential to evaluate the industrial risks within the host country. Aside from the well-established hydropower sector, other renewable energy sectors in Brazil are still in their infancy. Therefore, it is necessary to conduct a comprehensive analysis of the entire renewable energy generation industry. Industrial risks are quantified through five indicators: the proportion of renewable energy consumption relative to total energy consumption, the percentage of the population with access to electricity, the extent of transmission lines, the capacity for renewable energy generation, and *per capita* electricity consumption. These metrics provide insights into the host country's power industry market size, where a larger market size encourages investment.

Consideration of business environment risks is essential. Following the construction phase, the project progresses into the operational phase, where a robust business environment is crucial for the smooth execution of this stage, enhancing the implementation of the company's development strategy and yielding increased returns. Business environment risks encompass four key indicators: the number of domestic listed companies, the market capitalization of these companies, non-state participation in energy investment, and the robustness of the legal system. The first two indicators gauge the host country's commercial market development, which, if favorable, supports investment. The extent of non-state involvement in energy investment indicates private sector interest in the host country's energy prospects. The legal system metric measures market fairness.

However, the risk assessment indicator system developed in this study exhibits several limitations, primarily associated with the sources of the indicators. Specifically, the data for political risk indicators are exclusively sourced from Worldwide Governance Indicators (WGI); however, these data are generalized. Typically, different countries investing in Brazil may encounter varying

TABLE 7 Renewable energy investment risk measurement results.

Year	Comprehensive risks	Economic risks	Political risks	Industry risks	Business environment risks
2000	0.11	−1.3	0.77	−1.83	−1.31
2001	−0.16	−1.43	0.9	−1.56	−1.31
2002	−0.29	−1.49	1.03	−1.31	−1.097
2003	−0.36	−1.41	0.79	−1.08	−1.18
2004	−0.61	−1.26	0.21	−1.03	−1.33
2005	−0.82	−0.99	0.11	−0.87	−1.11
2006	−0.69	−0.69	−0.3	−0.69	−0.54
2007	−0.19	−0.21	−0.17	−0.35	−0.06
2008	0.01	0.16	0.3	−0.20	−0.395
2009	0.74	0.17	0.42	0.04	1.42
2010	0.95	0.9	0.85	0.15	1.26
2011	1.15	1.48	0.65	0.46	1.28
2012	1.16	1.29	0.49	0.49	1.88
2013	0.57	1.25	−0.02	0.57	0.42
2014	0.3	1.2	0.07	0.68	0.73
2015	−0.49	0.396	−0.41	0.69	−0.02
2016	−0.15	0.37	−0.46	0.85	0.54
2017	−0.33	0.68	−0.84	0.92	0.01
2018	−0.64	0.52	−1.48	1.17	−0.13
2019	0.13	0.44	−1.25	1.398	0.83
2020	−0.37	−0.07	−1.65	1.497	0.12

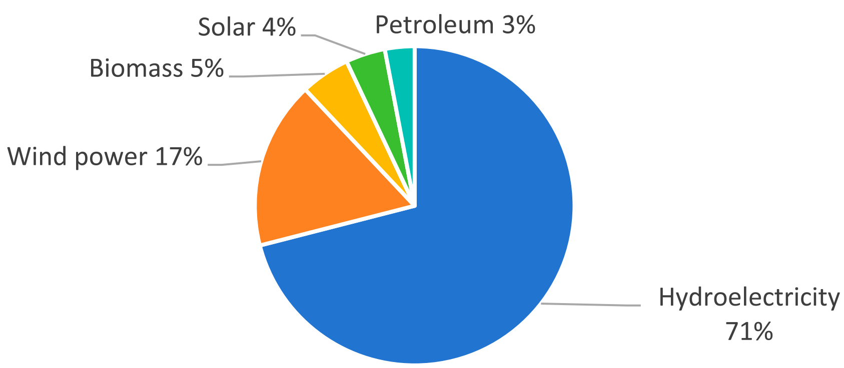

FIGURE 5
Installed capacity of each type of energy owned by Chinese companies in Brazil. Source: https://www.gov.br/aneel/pt-br.

political risks yet utilizing WGI data results in the identical political risk assessment for all investing nations, thus introducing constraints in accurately calculating political risks with WGI data. Additionally, other risk indicators are primarily derived from the World Bank and the Energy Research Company (EPE). Given the differences in statistical methodologies between these institutions, inevitable discrepancies in data accuracy occur. Furthermore, delayed data updates from the World Bank also limit timely risk assessment.

In conclusion, this research classifies risk factors into four principal categories: economic, political, industry, and business environment risks, with each category encompassing a set of secondary indicators. Notably, within the industry risk category, two specific secondary indicators pertinent to renewable energy investments are introduced: the proportion of renewable energy in total energy consumption and the generation of renewable energy electricity. The factor analysis technique is applied to perform a quantitative assessment of Brazil's investments in renewable energy electricity. This method isolates common factors from a multitude of complex variables, thereby condensing a vast array of original indicators into a limited number of comprehensive indicators. These common factors preserve the essential information from the original indicators, facilitating a more straightforward and intuitive evaluation of risks. Furthermore, the factor analysis will derive factors from all secondary indicators to quantify the primary indicators through these common factors.

Since secondary indicators are measured using different units and standards, it is not possible to analyze the data directly. To preprocess the secondary indicators, this paper uses the Z-score method to standardize all secondary indicator data. Following that, SPSS26 software is used to perform a factor analysis of the data.

6.2.2 Feasibility test of factor analysis data

In the domain of factor analysis, the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity are pivotal tools for evaluating the appropriateness of the original dataset for factor analysis. The KMO measure, which varies between 0 and 1, reveals the adequacy of factor analysis; a value above 0.5 suggests strong intercorrelations among variables, qualifying them for further analysis. The observed KMO value of 0.683 indicates a favorable factor analysis condition. Concurrently, Bartlett's test of sphericity, producing a significance value of 0, below the threshold of 0.05, supports the rejection of the null hypothesis that the indicators are uncorrelated, thereby validating their suitability for factor analysis.

6.2.3 Factor extraction

Principal component analysis is employed to derive common factors from various secondary indicators, where components possessing eigenvalues exceeding one encapsulate the majority of the information from the original indicators, thus minimizing significant information loss. In this research, the cumulative variance contribution rate of the four extracted common factors surpasses 90%, indicating substantial retention of the initial data's information. By rotating the initial factor loading matrix, the relationships between factors and original variables are redistributed, thereby enhancing the coefficients within the matrix to facilitate a more straightforward interpretation (Table 5).

6.2.4 Scoring coefficient matrix

After extracting the common factors, the scoring coefficient matrix can be obtained. This scoring coefficient matrix allows the direct derivation of expressions for each common factor (Table 6).

6.2.5 Obtain the comprehensive calculation result

After obtaining the score coefficient matrix, it is possible to calculate the investment risk of Brazil's renewable energy over the years. The formula is $I = \sum_{j=1}^{n} Z_j W_j$ among them I represents the overall risk, Z_j represents the score of the j-th indicator, W_j is the score coefficient of the j-th indicator, and n represents the number of indicators. The specific calculation formula is as follows:

$$F1 = 0.149 \times U1 + 0.133 \times U2 + \ldots \ldots 0.109 \times U18 + 0.141 \times U19$$

$$F2 = 0.043 \times U1 + 0.007 \times U2 + \ldots \ldots 0.157 \times U18 + 0.076 \times U19$$

$$F3 = -0.148 \times U1 - 0.085 \times U2 + \ldots \ldots 0.076 \times U18 + 0.021 \times U19$$

$$F4 = 0.030 \times U1 - 0.036 \times U2 + \ldots \ldots 0.270 \times U18 - 0.153 \times U19$$

Where F1 to F4 denote the scores of four common factor components derived for assessing the overall risk of renewable energy investment in Brazil, the scores for the comprehensive investment risk over subsequent years can be calculated. The formula for determining the total score of comprehensive investment risk is specified as follows:

$$F = (F1 \times 43.536\% + F2 \times 31.001\% + F3 \times 8.238\% + F4 \times 7.895\%) \times / 90.669\%$$

Economic risk, political risk, industry risk, and business environment risk can be obtained using the same method, where a higher score indicates a lower risk (Table 7).

To provide a more intuitive visualization of the changing trends in various risk types, the study compiled data on different risk types in order to create a line chart (Figure 6). According to the chart, political risk has gradually decreased since 2010, a period characterized by significant economic instability in Brazil, intense conflict among interest groups, and serious corruption concerns. The political landscape saw a major shift in 2010 with the election of Dilma Rousseff as Brazil's first female president. However, Rousseff faced accusations of budget irregularities, specifically manipulating fiscal data without congressional approval, which contravened fiscal responsibility laws. These allegations spurred widespread protests and political unrest, culminating in her impeachment by the Brazilian House of Representatives on 11 April 2016, for fiscal crimes. Rousseff was removed from office in August of that year, with Vice President Michel Temer assuming the presidency. In the 2018 elections, Jair Bolsonaro's victory signaled a rightward shift in Brazilian politics.

Since 2010, Brazil has undergone frequent political transitions, culminating in the lowest political risk scores observed.

Concurrently, economic risk and business environment risk scores reached their peak between 2010 and 2013, subsequently declining and stabilizing from 2016 to 2019. The economic downturn in 2014 exacerbated by inflation and rising unemployment, coupled with then-President Rousseff's fiscal irregularities, further deteriorated Brazil's economy, and business conditions. The situation showed signs of improvement following the inauguration of the current president in 2016. In 2020, with the exception of industry risk, all other risk scores declined, likely influenced by the COVID-19 pandemic, which negatively impacted Brazil's economy and social fabric, increasing investment risk in that year.

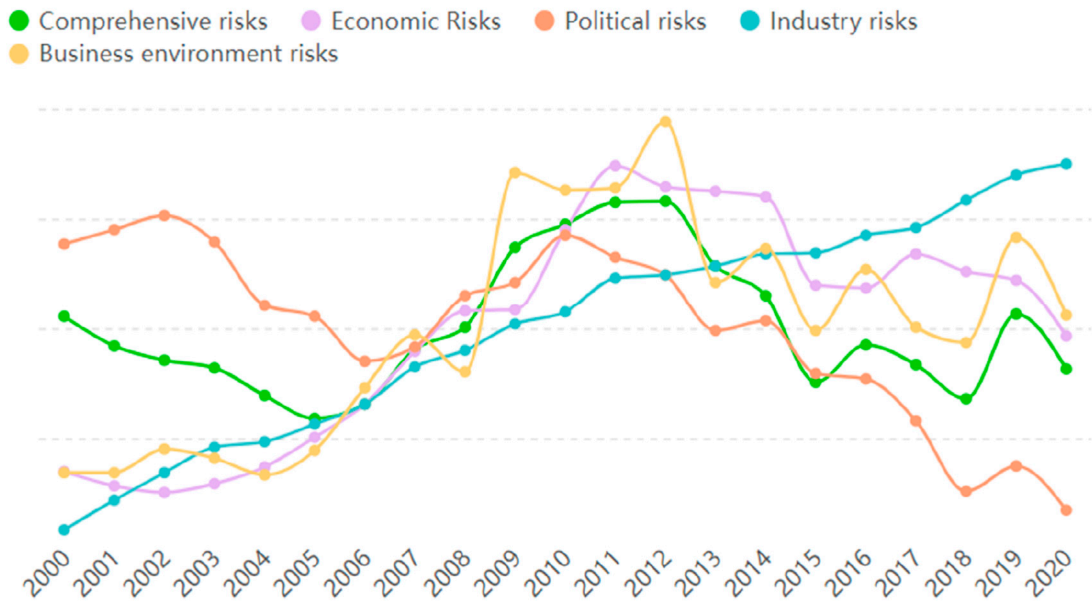

FIGURE 6
Renewable energy investment risk measurement results.

The industry risk score, however, has shown a consistent rise, driven by technological progress and social advancements that have expanded the generation and share of renewable energy. Additionally, Brazil's active implementation of various policies promoting renewable energy development has contributed to a gradual reduction in industry risk.

7 Conclusion and suggestions

7.1 Enormous development potential in wind and photovoltaic installation capacity in Brazil, suitable for Chinese enterprise investment

Analysis of historical data coupled with verification through grey forecasting models indicates a rapid expansion in Brazil's wind and photovoltaic installation capacity from 2023 to 2027. These forecasts, which align with the prevailing development trends in Brazil's renewable energy sector, hold significant reference value and suggest a likely emphasis on wind and photovoltaic power generation as primary focal points for Brazil's renewable energy industry. Meanwhile, China maintains a leading photovoltaics position globally. In 2022, the total output value of China's photovoltaic manufacturing sector exceeded 1.4 trillion RMB, with exports surpassing 51.2 billion USD. China has consistently led the world in polysilicon and photovoltaic component production for 12 and 16 consecutive years, respectively. Advances in technology and reductions in polysilicon energy consumption and wafer thickness have endowed Chinese electric power enterprises with cutting-edge technology, substantial capital, and a deep reservoir of experienced talent, thereby providing them with a distinct competitive edge in the Brazilian electricity market. This positions Chinese power companies to capitalize on this developmental opportunity, enhance cooperation with Brazil in renewable energy generation, and establish an innovative paradigm in Sino-Brazilian power cooperation.

7.2 Businesses should focus on preventing political risks

Results of the factor analysis indicate a significant decline in Brazil's political risk score in 2020 in comparison to 2000, suggesting a progressive increase in political risk. Brazil has experienced significant political instability in recent years, with corruption levels comparable to those of developed countries. Therefore, it is imperative that Chinese electric power companies assess political risk before making investments in Brazil. This research, therefore, offers the following recommendations concerning political risk:

1. By implementing a localization strategy, companies can recruit and train regional talent, facilitating better integration into the surrounding community. Local employees possess a profound understanding of the political landscape, enhancing the company's capacity to identify and mitigate potential political risks promptly. In addition, companies can reduce logistics costs by sourcing and selling products locally. Further reducing potential political risks is the establishment of long-term and stable relationships with regional suppliers and customers.
2. Companies may examine data published by authoritative institutions, such as the World Bank and the Worldwide Governance Indicators (WGI), prior to investing in a host country. By utilizing this data, they can analyze their

investment strategies and improve their capacity to identify high-quality projects.

3. Companies may explore overseas investment insurance services offered by China Export & Credit Insurance Corporation. Such insurance can effectively hedge against Chinese electric power companies' risks in their overseas investments, thereby minimizing potential losses.
4. Formulate innovative proposals for energy collaboration between China and Brazil by leveraging the advantages of comprehensive strategic partnerships between China and Brazil. The aim of this joint effort is to develop an innovative framework for the development of renewable energy that benefits the populations of both countries, contributes to addressing global climate change, and supports the battle for energy transition. Energy cooperation between China and Brazil will remain sustainable and stable as long as it benefits the societal development of both countries and the wellbeing of their citizens.

7.3 Chinese power companies should promote sustainable development goals (SDGs) and benefit local people through energy cooperation with Brazil

Renewable energy advancement is essential for fulfilling the United Nations Sustainable Development Goals (SDGs) and the forthcoming 2030 agenda. A wide range of objectives are included in these goals, including poverty eradication, economic development, and climate change mitigation. Through the utilization of renewable energy, industrial transformation can be driven, jobs can be created, poverty can be alleviated, and carbon emissions can be substantially reduced, thus benefiting both the local environment and global climate. Notably, the Amazon rainforest in Brazil, often referred to as the "lungs of the Earth," has experienced significant environmental degradation due to fossil fuel emissions. As a result, substantial investments in the development of renewable energy in Brazil are critical to improving the environmental conditions throughout the world. Chinese electric power companies are encouraged to deepen energy cooperation with Brazil through strategies such as promoting localization of operations, increasing local employment to stimulate job creation, actively engaging in public welfare projects, and benefiting the Brazilian populace, thereby fostering the sustainable development of energy in Brazil.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary Material.

Author contributions

FZ: Writing–review and editing, Validation, Supervision, Conceptualization. HW: Writing–original draft, Resources, Methodology, Investigation, Formal Analysis, Data curation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenrg.2024.1419583/full#supplementary-material

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