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The expansion of BRICS and its impact on the use of renewable energy sources: a case study of hydrogen energy

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ABSTRACT

Considering the increasing energy needs and environmental challenges in the world, BRICS members have also put in place a policy of reducing dependence on fossil fuels and moving towards more sustainable energy sources. This study aims to investigate the role and impact of the expansion of this bloc on the development and use of renewable energies, with a special focus on hydrogen energy. In this article, the combined method (quantitative and qualitative) and the theoretical framework of sustainable development and energy transition have been employed. Based on the results, BRICS can play an important role in accelerating the development of hydrogen energy by using policies such as knowledge and technology exchange between member countries, increasing investment in research and development of hydrogen energy, and financing hydrogen energy production infrastructure projects by the new BRICS Development Bank.

1. Introduction

Regional organizations have attracted the attention of the international community since the end of World War II due to their roles in global governance. The hegemony of the West led countries from various parts of the world to establish organizations that could represent their interests, particularly those in the global South, in the division between the North and South. One of these organizations is BRICS. The BRICS organization, which includes emerging global powers. BRICS is actually a group of emerging economic powers of the world, namely Brazil, Russia, India, China, and South Africa. Initially, the name of this group was called BRICS, but after South Africa joined, it was changed to BRICS. This organization has tried to expand its role in global equations by expanding economic cooperation or plans, such as removing the US dollar from its equations. The main text of the article discusses the structure and policies of BRICS. The issue of renewable energy has attracted the attention of the world due to the high cost and price fluctuations of fossil fuels, environmental problems, and the impact of crises. The presence of two energy consumption giants in the world, namely China and India, has led to the issue of energy and its sustainable supply being given attention. In this regard, China

and India are seeking to expand the use of renewable energy and reduce dependence on fossil fuels. The presence of the world's energy giants, namely China, India, Iran, and Russia, in this organization has made the role of energy and its policies very important in the BRICS organization. This study aims to investigate the role and impact of the expansion of this bloc on the development and use of renewable energies, with a special focus on hydrogen energy. In this article, the combined method (quantitative and qualitative) and the theoretical framework of sustainable development and energy transition have been used. Based on the results, BRICS can play an essential role in accelerating the development of hydrogen energy by using policies such as knowledge and technology exchange between member countries, increasing investment in research and development of hydrogen energy, and financing hydrogen energy production infrastructure projects by the new BRICS Development Bank. Renewable energy-led growth hypothesis: New insights from BRICS and N-11 economies. It has been argued that although BRICS and N-11 economies have experienced tremendous economic growth in recent years, the energy required is mainly consumed from conventional sources. Therefore, policymakers have turned their attention towards promoting

the production and consumption of renewable energy in all economic activities. The findings of this paper show that the renewable energy-based growth hypothesis is present in BRICS countries in AMG and in all quantiles in MMQR, but surprisingly, it is absent in N-11 economies using both estimates [1].

Perspective of renewable energy in the BRICS countries: The BRICS countries (Brazil, Russia, India, China, and South Africa) have separately embarked on a transition to sustainable energy sources. Khare et al. [2] examined the renewable energy networks of the BRICS countries. It compares and assesses the potential of different renewable energy technologies. The study presents the positive and negative impacts of renewable energy on economic development, foreign investment, domestic production, energy sustainability, and environmental protection across all BRICS countries.

Examining the drivers of renewable energy consumption, evidence from BRICS nations: Sachan et al. [3] studied the factors affecting renewable energy consumption by analyzing data from BRICS countries from 1990 to 2015. Panel quantile regression methods and other robustness tests show that the environmental policy stringency index and the human development index have a significant and positive effect on renewable energy consumption. Other variables, including carbon dioxide emissions and gross fixed capital formation, show a statistically significant and negative relationship with renewable energy consumption.

Role of renewable energy investment and geopolitical risk in green finance development, empirical evidence from BRICS countries: Renewable energy-led growth hypothesis: New insights from BRICS and N-11 economies. Dong et al. [4] employed panel data from BRICS countries from 2000 to 2020 to examine the interactions among economic growth, green finance, green credit, renewable energy investment, and geopolitical risk (GPR). Furthermore, the findings of the paper show that renewable energy adoption in BRICS countries is significantly and favorably affected by GPR.

As studied and reviewed, no article has addressed the use of hydrogen energy from various types of renewable energy and the impact of BRICS on expanding its use, and this has made this article even more important.

2. Theoretical framework

Growing environmental concerns and the rising economic costs associated with fossil fuel dependence have accelerated global attention toward renewable and clean energy solutions. This shift aligns with both sustainable development objectives and international climate commitments. Energy transition represents a long-term, strategic process that necessitates tailored approaches, incorporating context-specific technologies and policies to achieve net-zero emissions while balancing national energy security and economic considerations. From an analytical perspective, while environmental protection remains a central driver of energy transition, the process must also account for critical factors such as energy security and economic viability—particularly for resource-rich nations, including those within the BRICS bloc. At the international level, organizations such as the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) have identified six key pillars for successful energy transition:

- Expansion of renewable energy infrastructure
- Enhancement of energy efficiency and demand-side optimization

- Strategic electrification of energy systems
- Integration of hydrogen as a clean energy carrier
- Implementation of carbon capture technologies for fossil-based systems
- Bioenergy with carbon capture and storage (BECCS)

Energy transition, as a transformative process within energy systems, has been examined through various theoretical lenses by prominent scholars. Below, we outline the most significant theoretical frameworks in this field.

2.1 Socio-technical systems theory

Frank Geels and Johan Schot [5] pioneered this theoretical approach through their Multi-Level Perspective (MLP) framework. They conceptualize energy transition as the outcome of interactions across three levels:

- Niche level (emerging technologies)
- Regime level (dominant energy systems)
- Landscape level (macro-political, economic, and social trends)

2.2 Governance of energy transitions theory

Anadon and Nemet [6] emphasized the critical role of policy-making and institutional frameworks in accelerating or impeding energy transitions. Their work highlights how regulatory structures, subsidies, carbon pricing mechanisms, and market regulations determine the pace of transition.

2.3 Path dependency theory

Pierson and Arthur [7] demonstrated that energy systems exhibit inertia due to sunk costs and entrenched infrastructure, leading to resistance against rapid shifts. This theory explains why some nations lag in adopting renewable energy despite global pressures.

2.4 Political economy of energy transitions

Timothy Mitchell [8], in his seminal work *Carbon Democracy* (2011), argues that energy systems are not merely technological but deeply political. He asserts that a successful transition requires transformations in power relations and the political structures governing energy.

2.5 Energy Justice Theory

Benjamin Sovacool et al. [9] advocate for a socially inclusive approach to energy transitions, emphasizing three core principles:

- Distributive justice (equitable allocation of costs and benefits)
- Procedural justice (public participation in decision-making)
- Recognition justice (respect for marginalized communities' rights).

Figure 1 illustrates the conceptual model of the study's theoretical framework. Within the theoretical framework of sustainable development, greenhouse gas mitigation and environmental preservation emerge as fundamental imperatives, particularly for major emerging economies like the BRICS nations. Notably, BRICS countries have demonstrated a strong commitment to renewable energy advancement, with hydrogen economic development receiving particular emphasis as a strategic priority. The convergence of sustainable development principles and energy transition strategies provides a robust analytical foundation for examining the energy policies of BRICS members. These frameworks are particularly relevant given the bloc's concerted efforts to harmonize climate objectives with energy security and economic growth imperatives,

making them indispensable to any scholarly examination of contemporary energy geopolitics.

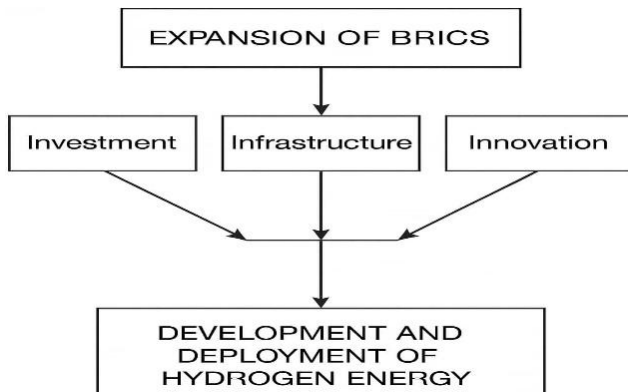


Figure 1. Conceptual model of the theoretical framework

3. Hydrogen energy as an alternative fuel

The rise of global warming caused by the emission of greenhouse gases, especially carbon dioxide, and the emergence of environmental crises, the limitation of fossil fuel resources, and the increase in world population growth as three sides of a triangle, have required countries to revise their energy policies and prevent the collapse of human societies under the influence of the reduction of fossil fuel resources. Although during the corona virus pandemic, the amount of crude oil production in the world decreased significantly due to transportation restrictions and reached 88 million barrels per day according to the Statista report, it is still observed that during the last two decades, the amount of crude oil production has made a big jump and has reached from 74.570 million barrels in 2000 to 96.376 million barrels per day in 2023 [10], which is the highest amount in this period. Therefore, in order to reduce the global emissions of these gases, the process of "decarbonization", which means energy transition from fossil fuels to low-carbon energy sources, is the only solution that must happen.

As can be seen in Figure 2, in 2023, the three non-renewable energy sources of oil, coal and natural gas account for the largest amount about 75% of the share of energy supply in the world, while renewable energy sources such as nuclear, Wind, solar and hydropower have produced nearly 17% which is only a small percentage of the world's energy. This means that the energy transition is in its early stages and has not been fully implemented by countries. Among the clean and sustainable energy sources, hydrogen is considered a suitable alternative to fossil fuels. Hydrogen, represented by the chemical symbol H, is a chemical element in the periodic table with atomic number 1 and has three isotopes, namely protium, deuterium, and tritium [12]. Hydrogen is the most abundant chemical substance in the world, which makes up approximately 75% of the mass of the world and is found in molecular forms such as water and organic compounds. As can be seen in Table 1, there are 8 different types of hydrogen, among which green hydrogen is the most suitable type for energy supply. Although hydrogen is known as the lightest element, it has the highest amount of energy per unit weight among all fuels [13].

In the last decade, according to energy reports published by Statista [15], many countries such as Australia, Germany, Spain, the Netherlands, and the United Kingdom have made the transition from an economy based on fossil fuels to the hydrogen economy. In the list of the top 10 countries that have the largest number of green hydrogen production facilities around the world, the names of China and Russia are also visible. The Russian Federation and China are two leading countries in the BRICS group in the field of hydrogen policy and projects. In Figure 3, the components that an economy transitioning to a hydrogen economy should pay attention to are categorized. One of the most essential points to pay attention to in the hydrogen energy system is choosing the right source for hydrogen production. To achieve a sustainable and environmentally friendly hydrogen economic system, the required hydrogen energy must be produced from clean, abundant, accessible, and affordable sources. As can be seen in the diagram, hydrogen production sources can be divided into renewable and non-renewable sources or fossil fuels.

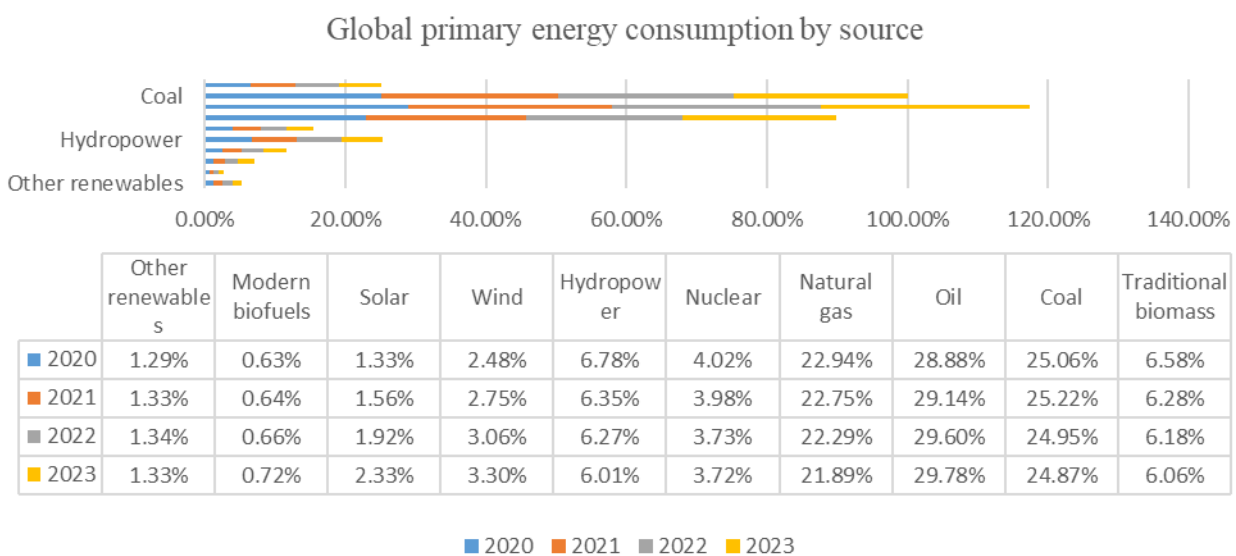


Figure 2. Global primary energy consumption by source [11]

Hydrogen production from renewable sources such as geothermal, water, wind, solar energy, and biomass accelerates the decarbonization process and significantly reduces environmental pollution.

Table 1. Different types of hydrogen [14]

Grey hydrogen	Gray hydrogen, the most commonly known form of hydrogen production, is created using natural gas or methane and methane steam reforming, without absorbing greenhouse gases.
Blue hydrogen	Like gray hydrogen, blue hydrogen is produced from natural gas using a steam reforming process that combines natural gas and heated water in the form of steam.
Green hydrogen	Green hydrogen is produced using renewable energy sources such as solar or wind energy, and this type of hydrogen is produced using the electrolysis process that splits water into hydrogen and oxygen.
Black and brown hydrogen	In the production of this type of hydrogen, which is the opposite of green hydrogen, black coal or brown coal is used, and for this reason, the most damage to the environment occurs in this type of production process.
Turquoise hydrogen	Newly entered into this category, turquoise hydrogen is made using a process called pyrolysis of methane to produce hydrogen and solid carbon, and in the future, it may be valued as a low-emission hydrogen.
Pink hydrogen	Pink hydrogen produced through electrolysis with nuclear energy can also be called purple hydrogen or red hydrogen. Since CO ₂ gas is not released in the production process of pink hydrogen, it is usually considered as green hydrogen.
Yellow hydrogen	Yellow hydrogen is the term used to produce hydrogen through electrolysis using solar energy.
White hydrogen	White hydrogen, which is a form of natural hydrogen, is found in underground deposits and is created through the process of fracking. But so far there is no suitable method to use this hydrogen production.

Hydrogen production systems must be efficient on small and large scales and be available in a fixed and portable form. According to Pareek et al. [16], there are several paths of hydrogen production such as Steam methane reforming, In this method, which uses natural gas extracted from the earth's crust as an energy source, extracted methane can be combined with steam using thermal processes such as steam methane conversion and partial oxidation to produce hydrogen. Coal gasification, Coal gas can be converted into energy, liquid fuel, chemicals and hydrogen in a process where coal reacts with hydrogen (H₂), oxygen (O₂) and steam under high pressure and constitutes a mixture of carbon monoxide and hydrogen. Electrolysis, In this process, by the application of electrical current, water splits into hydrogen and oxygen. Photoelectrochemical, in this method, hydrogen is produced from two abundant renewable sources such as water and sunlight. In this process, two electrodes are used in which one electrode acts as an anode for oxygen production and the other electrode acts as a cathode for hydrogen production. Thermochemical water splitting, Thermochemical processes, whose heat can be provided by nuclear or solar sources, is a chemical reaction that produces hydrogen at high temperatures (500-2000 degrees Celsius).

In cases where the source of hydrogen production, such as solar energy, is not permanent and continuous, a suitable storage system is required in hydrogen production. The produced hydrogen can be stored in different ways such as Chemical hydrides, Compressed gas, Cryogenic liquid and Metal hydrides. The main expectations from the hydrogen storage system can be specified as high power generation, low electricity and energy consumption, zero emission of pollutants, availability, effective operation, long life and minimal hydrogen waste during discharge and storage [17]. Among the most important fields of application of the final hydrogen energy produced are chemical industries, electricity production, transportation and construction. Since the transportation sector in the world remains largely dependent on fossil fuels and the share of this sector in the global production of carbon dioxide according to Figure 4, especially cars, is more than 48% in 2022, one of the applications of Hydrogen energy can be considered in the transportation sector. By substituting hydrogen fuel instead of fossil fuels, the pollutants in the transportation sector will be significantly reduced.

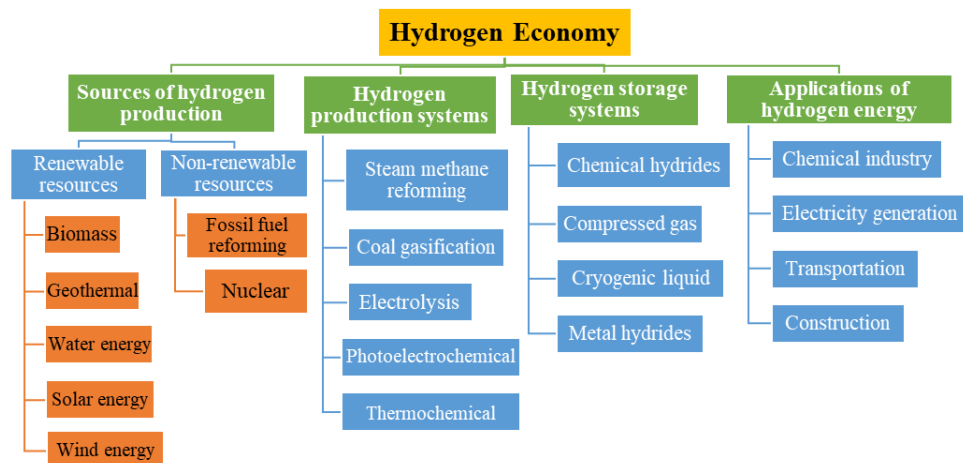


Figure 3. The hierarchy of a hydrogen economy

carbon dioxide emissions produced by the transportation sector worldwide. 2022

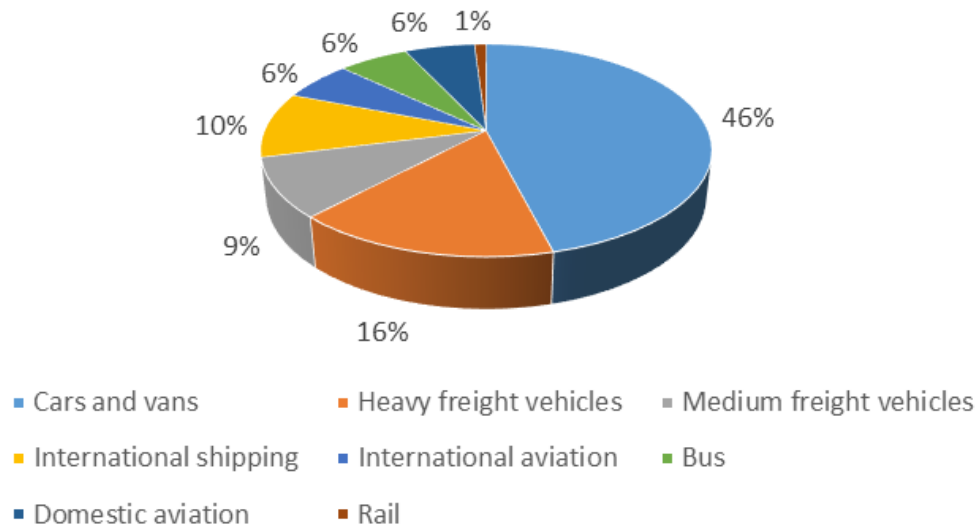


Figure 4. CO₂ emissions by transportation [18]

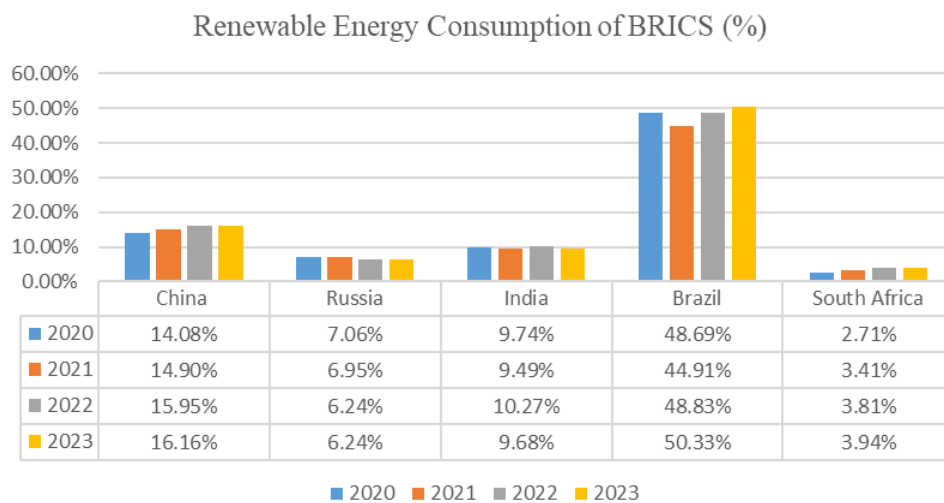
4. Performance of BRICS (old and new mem) in hydrogen energy projects

One of the important issues that has become the concern of developed and developing countries is establishing a balance between economic growth and environmental issues [19]. The increase in greenhouse gas emissions has forced the countries that have become the largest consumers of fossil fuels due to their economic growth to look for ways to achieve the transition to a green and low-carbon economy. Since countries with emerging economies are experiencing a stage where achieving economic growth and well-being is a priority for them over environmental well-being, policies such as decarbonization, reducing dependence on fossil fuels, and replacing them with clean fuels are more challenging [20]. The BRICS member countries, which increased to 10 countries from 2024, can be considered as an example of emerging economies that directly face the priorities related to economic growth on the one hand and environmental issues on the other hand. Table 2 indicates variables such as the amount of carbon dioxide emissions and each country's share in global emissions for former BRICS members and countries that newly joined this organization in 2024. China, with the largest population and the largest amount of carbon dioxide production, with 12.667.428.430 billion tons in 2022, is ranked first, and Ethiopia ranks tenth among these countries with the lowest amount of carbon dioxide production of 21,106,910 million tons. According to the table, the amount of carbon dioxide emission by the main BRICS members, except India, first increased and then faced a noticeable decrease. But the new members who have joined BRICS have all had an increasing trend in carbon dioxide emissions. Changes in the amount of carbon dioxide emissions in the BRICS countries can be due to the adoption of decarbonization strategies by these countries, which will be explained further. One of the most important steps of the transition from an economy based on fossil fuels to a green hydrogen economy based on renewable energy sources is the formulation of long-term and short-term policies and strategies in this field.

In this regard, the most important policies and agreements of the main BRICS members in the field of renewable energy projects, especially hydrogen, will be reviewed first, and then the situation of the countries that have recently joined BRICS will be examined in relation to decarbonization projects and hydrogen policies. As can be seen in Figure 5, the percentage of renewable energy consumption of BRICS members in China, Brazil, and South Africa has maintained its upward trend since 2020. But this trend has been accompanied by fluctuations in Russia and India, and in 2023, due to the increase in carbon dioxide emissions by both countries, they have experienced some reduction in the consumption of renewable energies. Among BRICS members, it can be seen that Brazil has the highest amount of renewable energy consumption, and South Africa has the lowest amount. In recent years, the BRICS countries have increasingly cooperated in the field of energy and decarbonization of their economy. Following the BRICS summit in Johannesburg in 2018, the leaders of the five countries adopted a joint Johannesburg Declaration, which called for full implementation of the Paris Agreement and the 2030 Agenda, noting that "the five countries will strengthen their energy cooperation, indicating a transition to a cleaner, sustainable energy system [22,23]. The BRICS countries are working together to promote renewable energy sources such as wind, solar, and hydropower. For example, in 2019, the BRICS Energy Research Cooperation Platform was created to expand cooperation in the field of energy research and promote the use of renewable energy sources (Communique Adopted in the BRICS Energy Ministers Meeting, 2021). BRICS members also cooperate closely with international organizations such as the United Nations Framework Convention on Climate Change (UNFCCC) and the International Renewable Energy Agency (IRENA) to promote sustainable development and climate change. In the meeting held by the BRICS members on June 23, 2022, virtually, under the chairmanship of the President of China, the leaders emphasized the cooperation of the BRICS members in the new era of global development [24].

Table 2. Fossil CO₂ emissions in BRICS members [21]

Country		Fossil CO ₂ Emissions (tons)	Population	CO ₂ emissions per capita	Share of World's CO ₂ emissions (%)
China	2022	12,667,428,430	1,425,179,569	8.89	34.94
	2021	12,717,655,300	1,426,437,267	8.92	35.08
	2020	12,037,316,110	1,426,106,093	8.44	33.20
India	2022	2,693,034,100	1,425,423,212	1.89	7.43
	2021	2,528,133,480	1,414,203,896	1.79	6.97
	2020	2,320,678,660	1,402,617,695	1.65	6.40
Russia	2022	1,909,039,310	145,579,899	13.11	5.27
	2021	1,932,695,430	145,836,175	13.25	5.33
	2020	1,789,251,420	146,371,299	12.22	4.94
Iran	2022	686,415,730	89,524,246	7.67	1.89
	2021	677,815,330	88,455,488	7.66	1.87
	2020	656,798,170	87,723,443	7.49	1.81
Saudi Arabia	2022	607,907,500	32,175,352	18.89	1.68
	2021	590,582,460	31,328,375	18.85	1.63
	2020	571,341,980	30,991,207	18.44	1.58
Brazil	2022	466,770,410	210,306,415	2.22	1.29
	2021	503,538,680	209,550,294	2.40	1.39
	2020	447,695,430	208,660,842	2.15	1.23
South Africa	2022	404,974,510	62,378,410	6.49	1.12
	2021	418,965,260	61,502,603	6.81	1.16
	2020	419,865,030	60,562,381	6.93	1.16
Egypt	2022	265,961,280	112,618,250	2.36	0.73
	2021	249,642,460	110,957,008	2.25	0.69
	2020	228,165,980	109,315,124	2.09	0.63
United Arab Emirates	2022	218,799,350	10,242,086	21.36	0.60
	2021	214,451,290	9,789,048	21.91	0.59
	2020	201,002,140	9,448,524	21.27	0.55
Ethiopia	2022	21,106,910	125,384,287	0.17	0.06
	2021	20,552,520	122,138,588	0.17	0.06
	2020	18,841,280	118,917,671	0.16	0.05

**Figure 5.** Renewable Energy Consumption of BRICS during 2020-2023

In this meeting, the latest report of the Intergovernmental Panel on Climate Change (IPCC) was mentioned, according to which "the triple crisis of climate change, biodiversity loss, and pollution is intensifying. There is an overview of the decarbonization and hydrogen strategy of the 5 main BRICS countries:

Regarding compliance with the Paris Agreement, Brazil announced strategic measures to meet its climate neutrality commitments by 2050, including zero illegal deforestation by 2028, restoring and reforesting 18 million hectares of forests by 2030, and encouraging the expansion of the national rail network [25]. Policymaking in the field of hydrogen energy has always been the focus of the Brazilian government in recent years. For example, in the National Energy Plan 2050 (PNE 2050), which was launched under the Ministry of Mines and Energy of Brazil in 2020 [26], hydrogen is also part of the Brazilian energy strategy. In the Brazil 2050 Energy Plan, published in 2021, the increase in quality, safety, transport infrastructure, and incentives for the adoption of innovative hydrogen energy technology are also considered. In Brazil's three-year national hydrogen plan 2025-2023, the country's strategy is defined by three time frames: until 2025, the establishment of pilot low-carbon hydrogen power plants throughout the country, the establishment of Brazil as a competitive low-carbon hydrogen producer, until 2030. and integration of low-carbon hydrogen hubs in Brazil by 2035.

Climate doctrine of the Russian Federation, approved by decree of the President of the Russian Federation of December 17, 2009. The Russian Federation signed the Paris Agreement on climate change in 2015, but only ratified it in September 2019. Decarbonization was not a priority as the country was able to meet the agreement's requirement to reduce its emissions compared to 1990. The first official document of the Russian government in the field of hydrogen energy was approved in 2020 under the title Roadmap for the development of hydrogen energy in Russia until 2024 [27]. During the implementation of the road map, in 2021, the Russian government approved another document called the concept of hydrogen energy development in Russia, which outlines the goals, tasks, initiatives, and critical measures for the development of hydrogen energy in Russia in the medium term until 2024 and long-term until 2035 [28].

As reported on behalf of India's Ministry of Environment, Forest and Climate Change, India submitted its Long-Term Low Emission Development Strategy to the United Nations Framework Convention on Climate Change (UNFCCC) in November 2022 [29]. The Indian government has taken measures such as promoting a sustainable lifestyle based on conscious consumption and reducing waste, as well as policies in the sectors of energy economy, transportation, and industry, to combat climate change. The Joint Statement 2022, released at the BRICS High Level Meeting on Climate Change, noted that India has launched a National Hydrogen Mission to produce hydrogen from clean energy sources to create alternatives to fossil fuels. The Joint Statement released at the BRICS High-Level Meeting on Climate Change in 2022 reported that China is pursuing proactive national strategies to address climate change. Based on exceeding the 2020 climate action target promised to the international community, China further announced a goal and vision to strive to peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060. In 2019, the phrase "promoting the implementation of hydrogen charging and refueling facilities" was included in China's "Government Work Report" for the first time [30]. According to the latest report of the International Energy Agency in 2021 [31], one of China's

projects in renewable energy is the Sinopec Green Hydrogen Plant, which aims to be the first green hydrogen project of the state-owned China Oil Company and produce zero carbon fuel from renewable sources.

South Africa is making progress towards its climate goals in response to the Paris Agreement. South Africa established a Presidential Climate Commission in 2020, adopted a National Strategy, introduced an enhanced mitigation system with robust monitoring and assessment, and developed a long-term low-emission development strategy [32]. South Africa has shown interest in hydrogen energy since 2007. In 2021, a report on power fuels and green hydrogen was published by the country's Council for Scientific and Industrial Research (CSIR) [33]. Then, in a speech on 17 February 2022, the Minister of Higher Education, Science and Innovation of the Republic of South Africa announced the launch of the Hydrogen Society Roadmap (HSRM). Finally, in February 2022, the South African Hydrogen Community Roadmap (HSRM) was published by the South African government [34].

Egypt is one of the five countries that recently joined BRICS. Egypt's membership, because it is the largest non-OPEC oil producer in Africa and the second largest gas producer on the continent, can have many advantages for BRICS members, especially in the energy sector. As one of the leaders of the Arab world, Egypt plans to increase the supply of electricity produced from renewable sources to 42% by 2035 [35], so Egypt's experience in this field should accelerate the transfer of clean energy in other BRICS member countries. It should be noted that in the last few days, on August 15, 2024 and at the time of writing this article, Egypt has unveiled a national low-carbon hydrogen strategy with the aim of strengthening its green economy and achieving climate change goals [36]. As a new member of BRICS and Africa's sixth-largest economy, Ethiopia has grown at an average of 10 percent annually over the past 15 years [37]. Ethiopia has significant potential for energy installations and is capable of generating more than 60,000 megawatts (MW) of electricity from hydro, wind, solar, and geothermal sources [38]. About 90% of Ethiopia's production capacity is made up of hydropower, and wind and thermal resources make up 8% and 2%, respectively. Ethiopia has formulated its Climate Resilience and Green Economy Strategy (CRGE) with the goal of keeping greenhouse gas emissions low and building climate resilience and achieving middle-income status by 2025 [39]. In its energy policies, Ethiopia has also paid attention to the production of clean and hydrogen energy. In this regard, Ethiopia's Ministry of Water and Energy (MoWE) has announced that research on green hydrogen production is underway as a solution to meet the world's growing energy needs [40].

The Islamic Republic of Iran, as a country that has the largest oil reserves in the world, with the fourth rank, as well as large gas reserves, is considered one of the new BRICS members. The potential of different regions of Iran in wind, solar, and geothermal energy can provide the basis for the development of Iran's energy markets among BRICS members. Despite having significant amounts of minerals as well as renewable resources, Iran has not been able to invest properly in energy production from renewable sources due to severe economic sanctions. Saudi Arabia is the most powerful new BRICS member as the largest Arab economy with an annual GDP of more than one trillion dollars [41]. Despite Saudi Arabia's dependence on traditional fossil energy markets, the country also has goals in the renewable energy sector and aims to provide 50% of its electricity from

renewable sources by 2030 [42]. Saudi Arabia is a country with a huge potential for clean hydrogen production and, therefore, is exploring ways to become the largest supplier of blue and green hydrogen in the world and targets clean hydrogen production of 2.9 million tons per year. 2030 and 4 million tons per year by 2035 [43].

The United Arab Emirates has joined the BRICS as one of the top three energy powers of the Persian Gulf. In addition to being one of the top 10 oil producers in the world, the UAE recently announced plans to triple the share of renewable energy in the economy in line with the UAE Energy Strategy 2050 [44]. According to its strategy, the United Arab Emirates plans to use 44% of renewable energy, 38% of gas, 12% of clean coal, and 6% of nuclear energy sources to produce half of its electricity by 2050. In relation to hydrogen energy, the UAE has set its national hydrogen strategy 2050 to support local low-carbon industries and promote the UAE's position as one of the largest hydrogen producers by 2031 [45]. According to the Global Hydrogen Review 2023 [46], the UAE's strategy includes forecasting the production of 1.4 million tons of hydrogen by 2030, 7.5 million tons by 2040, and 15 million tons by 2050, through a combination of electrolysis with renewable and nuclear electricity, and natural gas, by absorbing, using, and storing carbon.

5. Role of BRICS in expanding hydrogen energy among member countries

The challenges BRICS members face in achieving clean energy, especially hydrogen, can be divided into two categories: internal and external. Internal challenges can be considered as the presence or absence of policies, potential, and infrastructure of countries in the field of hydrogen energy. External challenges also include factors influencing a country's policy-making, such as sanctions and shocks, as well as the establishment of bilateral and multilateral relations between BRICS members and the lack of a unified strategy among them. Among the former members of BRICS, Brazil is the country with the highest consumption of renewable energy and can be considered a leader in the transition to a hydrogen economy. About the new members who have recently joined BRICS, it can be said that Iran is considered a country that has not made adequate progress and investment in the field of renewable energies despite its great potential and resources. In general, because the process of energy transfer involves investment, social and political issues that are very different in each country, the transition from fossil fuels to renewable sources such as hydrogen energy, which requires the creation of appropriate infrastructure, is not a simple matter. One of the main challenges of BRICS is the geographical distance among members, very different socio-economic and legal models, as well as the competition among group members in influencing the energy market. Therefore, it seems difficult and almost impossible for BRICS to integrate the direction of member countries in obtaining hydrogen energy by formulating a general strategy.

Therefore, according to the existing challenges, the main question of the article can be answered here, which is "How can BRICS expand the use of renewable energy sources, especially hydrogen energy, in the member countries?" The three main components of the transition from fossil fuels to renewable energies can be categorized as follows: To achieve clean hydrogen production, a country must have the three I's: investment, infrastructure, and innovation. One of the unique features of BRICS that can act as a catalyst to accelerate long-term and expensive projects is the BRICS Development Bank. This bank, which was established in 2015 by 5 main members,

plays a vital role in financing and supporting the infrastructure and development projects of BRICS member countries (Brazil, Russia, India, China, and South Africa). The role of the BRICS Development Bank in providing its members with access to hydrogen energy production can be categorized as follows:

- **Funding projects:** The BRICS Development Bank can lead major projects in this field in member countries by providing the necessary financial resources for research and development of technologies related to the production, storage, and distribution of hydrogen.
- **International cooperation:** The BRICS Development Bank can act as a bridge between member countries to exchange knowledge and technologies related to hydrogen to accelerate the development of hydrogen infrastructure.
- **Encouraging private investment:** The BRICS Development Bank can encourage private sector investment in the field of hydrogen energy by providing financial guarantees and facilities.
- **Government policy support:** The BRICS Development Bank can help member countries optimize their national policies and strategies to achieve hydrogen energy by providing advice on financial, environmental, and industrial policies.
- **Eco-industrial park plan:** The BRICS Development Bank, by building eco-industrial parks in member countries, can help in the production of hydrogen and realize the goals of sustainable development in these countries simultaneously.

6. Conclusion

In recent decades, issues such as the increase in environmental pollution caused by non-renewable fuels and fossil fuel price fluctuations on the one hand and the benefits of renewable energy sources, such as the absence of pollution or their permanent availability on the other hand, have expanded the desire of many countries in the world to replace non-renewable energy sources in their energy sector. Among the types of clean renewable fuels, hydrogen energy has become a sustainable energy source because it can be produced from renewable sources such as water, solar, and wind energy, and is considered the best alternative fuel. Since the members of BRICS are countries with emerging economies, the issue of using renewable energy in the form of long-term and short-term policies and strategies has also received the attention of this bloc. By analyzing the energy policies and carbon dioxide emissions of each of the former and new BRICS countries, this article has examined the ways to promote and develop hydrogen energy in these countries. The findings of the research show that the new members of BRICS, such as Iran, Saudi Arabia, Ethiopia, Egypt, and the United Arab Emirates, have suitable conditions for the development of hydrogen energy production, but some of them are facing problems in the investment and infrastructure sectors. While the former BRICS members have taken a little step forward in the transition to clean energy under the influence of the Paris Agreement, Brazil, among them, can take the leadership role. Despite the fact that the current state of hydrogen development is still in its early stages and due to the high cost of hydrogen production, significant investment in the infrastructure and technology of this fuel is necessary to achieve its full potential. The BRICS Development Bank can finance the project, encouraging private investment as well as building eco-industrial parks to accelerate this process.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically concerning authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the corresponding author.

Conflict of interest

The authors declare no potential conflict of interest.

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