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Patenting for profitability: green energy innovations and firm performance in BRICS countries

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Introduction: Despite the significant advancements in renewable energy technologies, the current energy system remains heavily reliant on fossil fuels. However, an increasing number of studies have demonstrated that the proliferation of "green" patents is contributing to the transition towards a more sustainable energy future, with important implications for both environmental sustainability and corporate financial performance.

Methods: Utilizing panel data sourced from 63 of the most prominent energy sector companies within the BRICS countries during the period between 2011 and 2020, we conducted a comprehensive analysis with the objective of uncovering the distinct impacts of various types of patents in renewable energy technologies on the firm's financial performance indicators (ROA, ROIC, and market capitalization) by using multiple regression modeling.

Results: The feasible generalized least squares estimations reveal that higher CO2 emissions correlate with lower return on assets, ROIC, and market capitalization of energy companies, significant at the 5% level. Additionally, while renewable energy technologies (Y02E10) did not impact ROA, they contributed significantly to ROIC at the 1% level. Combustion technologies with mitigation potential (Y02E20) positively influence all financial performance indicators, and nuclear energy technologies (Y02E30) significantly contribute to both ROA and ROIC at the 10% level.

Discussion: Our research demonstrates that technological advancements in national economies are not consistent and that disparities exist in specific data segments. Advancements are observed in certain areas, highlighting the significance of national legislation in promoting green finance and renewable energy development. This emphasizes the need for BRICS countries to prioritize renewable energy technologies and adopt legislative initiatives from developed nations as a model for achieving clean technological growth and renewable energy targets.

KEYWORDS

GHG emissions reduction, green innovation, emerging countries, green energy, BRICS, firm performance

1 Introduction

At the UN Conference on Energy Allocation 2023 (COP28), a key moment was the global consensus of nearly 200 countries on the transition from fossil fuels to renewable energy, emphasizing their commitment to invest in renewable energy. This agreement marked a significant shift in international climate policy and demonstrated the growing recognition of the urgent need to mitigate climate change.

Despite the significant progress in renewable energy technologies, the global energy system remains heavily reliant on fossil fuels. In 2019, fossil fuels, including oil, coal, and natural gas accounted for more than 81 percent of global energy production (IAE, 2020). By 2025, this share is projected to fall to 75 percent and the share of renewable energy in global energy production is projected to reach 35 percent (IEA, 2023).

A recent study by (Şanlı et al., 2023) shows that in OECD countries, renewable energy sources (RES) and non-renewable energy sources (NRE) have an asymmetric effect on emissions in the long term, but not in the short term. The study suggests prioritizing renewable resources for a sustainable, low-carbon environment in OECD countries.

The development of innovative sustainable energy technologies or "green" patents primarily drives the transition to clean energy. In recent years studies have demonstrated that "green" patents incentivize research and development in sustainable technologies by granting exclusive rights to innovations and stimulating investment in green innovation (Urbanec et al., 2021). The presence of "green" patents indicates a company's dedication to corporate social responsibility and environmental sustainability offering proof of proactive initiatives. Finally, "green" patents play a crucial role in knowledge spillover, technology transfer, and the diffusion of green technologies, contributing to sustainable innovation policies and green growth (Aiello et al., 2021; Nie et al., 2022). The identified trends in green patenting in the BRICS countries highlight the potential of green innovation to contribute to sustainable economic development and environmental protection (Chien et al., 2021; Du et al., 2023; Udeagha and Muchapondwa, 2023).

According to the analysis by the International Energy Agency (IEA), investments in the renewable energy sector have outpaced those in other sectors of green energy. This indicates a widespread recognition of the immense potential and benefits associated with renewable energy sources. However, as depicted in Table 1, investments in the renewable energy sector witnessed a notable decline in 2020, decreasing by approximately USD 10 billion, which is equivalent to a 3.2% year-on-year drop. The decrease can be attributed to the economic difficulties caused by the COVID-19 pandemic in 2020. This resulted in a decline in business operations and global production, negatively impacting various industries around the world. Concurrently, the proportion of clean energy investment in relation to total investment increased by 5% in 2020 compared to 2019. Therefore, the decline in the absolute value of renewable energy investment primarily stems from the overall decrease in investments over the past year, whereas in relative terms, green investments have actually increased.

In the corporate sector, investments in green energy at the company level are relatively modest when compared to global investments. For instance, in 2019, global corporate investment constituted only 1.9% of the total investment in renewable energy. During the same year, investment in renewable energy accounted for just a third of the investments made in traditional energy sources such as oil and gas (refer to Table 2). Furthermore, corporate research and development (R&D) expenditures remain fairly stable.

To gain a deeper understanding of green investment, we turn our focus to investment at the national level. The data presented in Table 3 reaffirms the decrease in investment in 2020 compared to 2019. Among the actors listed in Table 3, the European Union (EU), China, and, to a lesser extent, India stand out as the top performers in terms of renewable energy investment. These countries exhibit a greater commitment to the renewable energy sector than to conventional energy. In 2020, EU investments in green energy were nearly 3.5 times higher than their investments in conventional energy. Conversely, China reduced its investment in oil and gas by approximately 41% in 2020, illustrating that green technology, though expensive, sometimes appears more plausible for companies than paying fines to maintain emission levels. However, this short-term strategy can have dire long-term consequences for a company.

In academic research, the identification of factors influencing corporate carbon emissions is critical for enhancing carbon performance. Factors such as environmental protection expenditures and innovation in green technology have been proven to affect the financial performance of heavily polluting enterprises (Tang et al., 2022). There are varying perspectives on the financial consequences of green innovation. Although the traditional perspective claims that investing in corporate

TABLE 1 Global investments in clean energy and their share of total investments (USD billion).

Investment sector	2015	2016	2017	2018	2019	2020
Renewable transport and heat	38	36	36	34	33	29
Renewable Energy	308	312	310	308	311	301
Nuclear energy	29	33	34	33	39	37
Solar Batteries	2	2	3	5	4	4
Carbon storage and capture	2	2	1	0	0	0
Share of investments in clean energy from total investments (%)	30	34	33	33	34	39

(Source: IAE).

TABLE 2 Global corporate R&D spending by selected sectors (USD billion).

Investment sector	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Oil and Gas	17.3	18.1	18.7	19.4	18.7	17.5	17.3	16.8	18.3	18.9
Renewable Energy	3.6	4.1	4.2	4	4.2	4.4	5	5.5	5.8	6.3

(Source: IAE).

TABLE 3 Investments in renewable energy sources and traditional energy (USD billion).

Country	Renewable energy		Oil and gas	
	2019	2020	2019	2020
China	92	88	78	46
United States	46	44	188	113
EU	49	45	19	13
India	18	14	15	12
Southeast Asia	13	10	31	22
Sub-Saharan Africa	6	9	32	23

(Source: IAE, with Bloomberg).

environmentalism negatively impacts financial performance, a more contemporary viewpoint asserts that embracing green innovation can actually enhance financial outcomes. By incorporating sustainable practices, businesses can witness an increase in revenues and a reduction in costs (Riehl et al., 2022). This shift towards environmentally friendly initiatives not only benefits the planet but also proves to be financially advantageous for companies. In summary, research indicates a positive relationship between corporate environmental performance, carbon emission disclosure, green innovation, and financial performance.

Other studies explore the connection between carbon emissions and financial outcomes, underscoring the potential positive effects of emission reduction on corporate returns (Ganda and Milondzo, 2018). Additionally, factors such as green strategy, corporate social responsibility disclosure, effective corporate governance, and financial performance have been identified as drivers of increased carbon emissions disclosure (Andrian and Kevin, 2021). Research has demonstrated that green innovation can lead to improvements in corporate environmental performance and positively impact financial results (D. Li and Shen, 2021). This encompasses the advancement of technologies and processes that promote energy efficiency, pollution mitigation, waste recycling, and the development of eco-friendly product designs (Chen, 2008). In fact, by reducing carbon emissions, adopting green strategies, and investing in green innovation, companies can enhance their environmental performance and potentially improve their financial performance.

Despite numerous studies on the impact of green patents on companies' financial performance, this issue has not been fully explored. The impact of green patents is mainly studied in comparison with that of mining technologies. At the same time, the development of renewable energy technologies has its own diversity. Therefore, it is necessary to study the impact of individual technologies and, more precisely, the impact of groups of renewable energy patents on the financial performance of companies.

In 2017, a study was conducted by (Noailly and Shestakova, 2017), which highlights the importance of carbon-free innovation in the energy sector. Their findings shed light on the potential benefits and implications of adopting carbon-free technologies in this crucial sector.

The lack of research on the relationship between specific technologies in renewable energy patents on the financial performance of companies constitutes a gap in the study of green innovation. The presented study is based on data from 72 companies in the BRICS countries. The results enrich the literature on the impact of green patents on financial performance and fill the research gap in the renewable energy industry.

The remainder of this study is structured as follows. The relevant literature review is presented in Section 2. Section 3 describes the econometric methodology, dataset and model used in the study. In Section 4, we present the empirical results. Section 5 concludes the article by discussing the findings.

2 Literature review

2.1 Global trends in green patenting

Renewable energy is a key focus of the study of green patents. Green patents, also known as environment-friendly patents, cover a broad range of innovations, including technologies for renewable energy, waste reduction processes, pollution control devices, and other environmentally friendly products and processes. Green patents are typically defined using internationally recognized classifications, such as the International Classification List of Green Patents issued by the World Intellectual Property Organization (WIPO) (Wurlod and Noailly, 2018). This classification system aids in identifying patents that make a specific contribution to environmental protection and resource conservation, and provides a standardized framework for identifying and classifying green innovations.

Green patents incentivize research and development in sustainable technologies by granting exclusive rights to their innovations and stimulating investment in green innovation (Guo et al., 2018). Additionally, green patents play a crucial role in knowledge spillover and technology transfer, facilitating the diffusion of green technologies and encouraging collaboration in sustainable innovation (Nie et al., 2022). The presence of green patents indicates a company's dedication to corporate social responsibility and environmental sustainability. They offer concrete proof of a company's initiatives to create and execute green technologies, showcasing a proactive stance towards addressing environmental issues and decreasing their ecological impact (Aiello et al., 2021). Green patents provide insight into the feasibility and effectiveness of green technologies, which influence the development and implementation of environmental regulations. This, in turn, contributes to sustainable innovation policies and green growth (Zhu et al., 2021).

To analyze trends in green patenting, (Urbaniec et al., 2021), measured eco-innovation and analyzed trends in green technologies based on environment-related patents in leading countries worldwide from 2000 to 2017. This study offers a comprehensive analysis of global trends in green patenting providing a valuable perspective on eco-innovation for nearly two decades. (Fujii and Managi, 2019). investigated the decomposition of sustainable green technology inventions in China highlighting the factors contributing to the growth of sustainable green technology patent publications. This study provides insights into specific green patenting trends in China, a key member of the BRICS group, and sheds light on the dynamics of green technological innovation in this country.

The reviewed studies concluded that renewable energy development is a rapidly growing technological area (Albino et al., 2014). conducted a patent analysis to elucidate trends in low-carbon energy technologies providing valuable insights into the trends and dynamics of green patenting in the energy sector.

Several studies have examined the relationship between renewable energy consumption, technological innovation, and environmental sustainability in the context of BRICS countries. For example, (Du et al., 2023), highlighted the role of green logistics and financial innovation in achieving carbon neutrality goals, emphasizing the potential of green innovation to increase the availability of renewable energy and mitigate environmental degradation in BRICS countries. Similarly, (Chien et al., 2021), propose an SDG framework for BRICS countries, highlighting the bidirectional causality between economic growth and ICT, which can play an important role in addressing environmental degradation. Furthermore, (Udeagha and Muchapondwa, 2023), point to the importance of fiscal decentralization, export diversification, and eco-innovation in achieving regional sustainability and carbon neutrality goals in the BRICS economies. This finding underscores the importance of green innovation in promoting sustainable economic development and environmental protection. Furthermore, (Majeed et al., 2022), suggest that financial globalization and green innovation can play an important role in increasing the share of renewable energy in BRICS countries, in line with the goals of the Paris Climate Agreement. This highlights the potential of financial mechanisms and technological advances in promoting renewable energy deployment and addressing environmental challenges. In addition, (Rahman et al., 2021), examine the role of energy consumption, economic growth, and globalization in environmental degradation in BRICS, showing that increased access to energy-efficient technologies through globalization can contribute to environmental sustainability in BRICS countries.

One interesting paper analyzing patenting trends in the renewable energy sector (Khurana and Bandyopadhyay, 2018). Analyzes the renewable energy policies of different countries. Governments and policymakers worldwide have introduced legislation and support mechanisms to accelerate the development of the renewable energy sector. Many countries have sectoral laws and regulations regarding the mandatory purchase of renewable energy and promotion of specific technologies. The identified trend shows that China is considered one of the largest centers of renewable energy development. This may be due to the fact that most inventors find a larger market here. Based on the analysis, it can be concluded that China has a well-structured renewable energy policy that stimulates its patenting activities.

A recent study using quantile regression (Anwar et al., 2021) has found that in ASEAN countries, non-renewable energy consumption stimulates carbon emissions in all quantiles, while renewable energy consumption reduces CO2 emissions in most quantiles. Similar results have been obtained for the top ten polluting countries (Sun et al., 2022). It was found that renewable energy consumption significantly reduces carbon emissions, especially in the extremely low and extremely high emission quantiles, and green innovation reduces carbon emissions, but mostly in the medium and high quantiles. The main conclusion of this research is the need for government incentives and subsidies for the use of renewable energy to combat environmental degradation.

The development of renewable energy has led to an increased interest in academic research. For example, (Teng et al., 2023), finds a positive relationship between green finance and innovation in renewable energy technologies. The asymmetric relationship between green finance and innovation in renewable energy technologies was analyzed in the top ten economies that encourage green finance. The results showed a positive relationship between green finance and innovation in renewable energy technologies in most economies in certain segments of the distribution. (Shen et al., 2020). used renewable energy patents as a proxy for green innovation and found that green innovation in renewable energy contributes to the reduction of air pollution and fossil energy consumption. Using Chinese provincial panel data, the authors applied a spatial measurement model to investigate the spatial impacts of green innovation in renewable energy and fossil energy consumption on air pollution in China from 2011 to 2017.

Green innovation and renewable energy technologies play key roles in paving the way for a low-carbon economy. They have a great potential to bring about meaningful changes and ensure a greener future.

2.2 The impact of green patenting on firm profitability

In addition to identifying the relationship between green patents and renewable energy innovations, firms' profitability and the use of green innovations deserve special attention. Several studies provide valuable information to assess the impact of green patents on firms' financial performance. (Wurlod and Noailly, 2018). found that green innovations have a positive impact on the energy intensity of industrial sectors, indicating the potential financial benefits for companies investing in green patents. (Hoang et al., 2020) also suggest that companies with green patents can earn higher profits and improve financial performance by increasing environmental transparency. Additionally, (Liu et al., 2020; Xu et al., 2021), demonstrated that R&D investment positively affects green

TABLE 4 Dependent, independent and control variables.

Variable	Description
Dependent variables	
ROA_{it}	Return on assets of company i in the year t
$ROIC_{it}$	Return on invested capital of company i in the year t
$MarCap_{it}$	Market capitalization of company i in the year t
Independent variables	
$CO2_{it}$	CO2 emissions by country i in the year t
$Y02E10_{it}$	Number of patents technologies of renewable energy generation - Y02E10 classification registered in country i by the year t
$Y02E20_{it}$	Number of patents combustion technologies with mitigation - Y02E20 classification registered in country i by the year t
$Y02E30_{it}$	Number of patents energy generation of nuclear origin - Y02E30 classification registered in country i by the year t
Control variables	
Rev_{it}	Revenue of company i in the year t
$CAPEXRev_{it}$	The ratio of capital expenditures (CAPEX) to revenue of company i in the year t
$R\&Dintensity_{it}$	The ratio of R&D expenditures to revenue of company i in the year t
ROE_{it}	Return on equity of company i in the year t
$GDPpc_{it}$	GDP *per capita* of country of company i in the year t

innovation performance and the number of patents for green inventions, further supporting the potential financial benefits of green patents. (Liu et al., 2021) applied the intellectual value-added coefficient model to measure financial competitiveness and found a positive relationship between intellectual capital investment and green innovation performance, indicating the potential financial benefits for firms investing in green innovation. They highlighted that green innovation activation, as measured by patent data, can influence financial performance and emphasized the importance of integrating green patents with other innovation activities to achieve optimal financial performance. (Przychodzen et al., 2020) have also examined the relationship between green patent ownership and financial performance, suggesting that firms with green patents may exhibit different levels of financial performance compared to firms without green patents (Marín-Vinuesa et al., 2020). While these studies provide valuable insights into the potential impact of green patents on financial performance, it is important to consider specific industries and firm characteristics (Dong et al., 2022). The importance of policymakers supporting the long-term development of green patents is highlighted, and the heterogeneous characteristics of listed firms are considered when designing green finance policies, suggesting a need for tailored strategies based on firm-specific characteristics (Dong et al., 2022). Furthermore, the question of how holding green patents affects firm productivity and economic growth has been raised, highlighting the need for a comprehensive understanding of the broader economic impact of green patents (Jovanović et al., 2022). In conclusion, a synthesis of these studies suggests that green patents can have a positive impact on firms' financial performance, particularly through increased environmental transparency, higher profits, and improved innovation. However, the specific effects may vary depending on the industry, firm characteristics, and integration of green patents with other innovation activities.

In addition to these, several studies have confirmed the positive effect of green patents on the financial performance of companies. For example, (Issa and Hanaysha, 2023), show a positive relationship between the use of renewable energy and a firm's financial performance, highlighting the benefits of carbon reduction for stakeholders. This study considers a panel dataset consisting of 1,919 observations of non-financial companies operating in thirteen European countries covering the period 2014–2021. The results show a positive relationship between renewable energy use and financial performance. In addition, the results show that some factors, such as the nature of the industry and environmental, social, and governance (ESG) controversies, influence this positive relationship.

(Tomczak et al., 2020) analyze the semiconductor and related equipment manufacturing sector and show whether investing in the components of solar technology manufacturers is a profitable business. To this end, the authors considered 62 financial ratios for a sample of 2,345 companies operating mainly in China. The companies in the sector are divided into two groups: "green" companies, whose production is related to renewable energy, and "red" companies, whose production is not related to renewable energy. These results are similar to those of other studies on renewable energy companies. Based on certain financial ratios, we find that green companies outperform red companies.

(Morina et al., 2021) highlight that most empirical studies have focused on the relationship between environmental and financial performance of renewable energy companies over the last two decades. This study identifies the drivers of profitability of renewable energy companies in the European Union (EU) between 2004 and 2018. This study examines the impact of company-specific, country-specific, and macroeconomic factors on the profitability of listed renewable energy companies headquartered in the EU. However, this study only covers the profitability of energy companies.

(Guan et al., 2021) provide evidence of a positive relationship between economic and financial development and the short-term use of renewable energy, particularly in the context of China. In addition, (Hassan, 2019), provides evidence that increased investment in renewable energy sources, combined with guaranteed favourable prices and volumes, stimulates the short-term financial performance of energy companies in OECD countries. Furthermore, (Behrens and Trunschke, 2020), found that citation-weighted patent stock has a significant effect on firm performance and market value, suggesting that patents, including green patents, have a positive impact on firm performance.

Contrary findings on the negative impact of green innovation on firms' financial performance were found in the following studies. For example, (Xie et al., 2022), examine the effect of green innovation on firm value and find that an increase in the share of green patent applications leads to a decrease in firm value in the short run. (Ruggiero and Lehkonen, 2017). show a negative relationship between renewable energy generation by electricity producers and short- and long-term financial performance. They use return on equity, return on assets, and the market value of the firm relative to total assets to measure financial performance and regress these on renewable energy production as the main variable. Furthermore, (Asri and Yusgiantoro, 2020), highlighted the existing challenge in energy source selection, where financial constraints exacerbate the dilemma between new and renewable energy (NRE) and non-NRE (fossil energy) sources. In an earlier study on this issue, (Tomczak et al., 2020), found that in most cases, there is no statistical difference between the financial situations of renewable energy companies and fossil fuel-only generation companies.

In conclusion, the relationship between renewable energy patents and financial performance is complex and multi-faceted. While some studies suggest a positive relationship, others are either negative or inconclusive. Factors such as economic development, policy incentives, and the nature of the energy industry play crucial roles in shaping this relationship.

Different approaches to assessing the impact of green patents on financial performance can be explained by the resource-based view (RBV). According to this view, companies gain a sustainable competitive advantage and improve performance by exploiting their unique resources and capabilities. However, in previous studies conducted before 2020, the use of green patents as a unique resource did not show any relationship, or the relationship was negative. Only with the growth of registered green patents were positive correlations found between green patents and financial efficiency, which is confirmed by evidence from developed countries and China. Thus, the development of renewable energy technologies is a unique resource for firms and should contribute to firm efficiency, including BRICS countries. This emphasizes the need for further investigating the impact of different types of renewable energy innovation in order to generate competitive advantages and improve profitability.

2.3 Hypotheses

Renewable energy sources have received significant attention owing to their potential impacts on carbon dioxide (CO2) emissions. Various studies have demonstrated that an increase in "green" patent applications for renewable energy technologies is linked to lower CO2 emissions (Li et al., 2020; Luo et al., 2021; Khan et al., 2022). Based on this established correlation, this study tests the hypothesis that the impact of "green" patents and CO2 reduction efforts have a dual effect on the firm's financial performance.

H1: *A higher level of CO2 emissions, ceteris paribus, negatively affects both accounting-based and market-based performance indicators of energy companies from BRICS countries.*

Previous studies claim that CO2 emissions deter corporate financial performance (Fujii et al., 2013; Chang et al., 2020; Marques et al., 2021).

H2: *Higher accessibility of technologies of energy generation through renewable energy sources (Y02E10/00), ceteris paribus, enhances market-based performance indicator of energy companies from BRICS countries.*

H3: *Higher accessibility of combustion technologies with mitigation potential (Y02E20/00), ceteris paribus, enhances both accounting-based and market-based performance indicators of energy companies from BRICS countries.*

We assume that access to renewable energy generation technologies allows companies to increase attractiveness for institutional investors and obtain subsidies from governments (Lee and Min, 2015; Liu et al., 2022), broadening their investment opportunities, and, as a result, enhancing market value. Moreover, higher number and accessibility of renewable energy technologies contributes to overall R&D activity in the energy sector (Noailly and Shestalova, 2017). However, in the context of BRICS countries, renewables are still less economically competitive sources of energy compared to developed countries, such as the US and the EU, which leads to insignificant contribution to short-term accounting-based performance.

H4: *Higher accessibility of nuclear energy generation technologies (Y02E30/00), ceteris paribus, enhances accounting-based performance indicators of energetic companies from BRICS countries.*

We assume that higher accessibility of nuclear energy technologies allows companies from BRICS countries to receive competitive advantages in terms of operating activity (Walker et al., 2021). However, the usage of nuclear energy may decrease the company's attractiveness for foreign institutional investors and ESG funds.

3 Methodology

A multiple regression model that utilizes panel data is employed to explore the impact of various types of renewable generation patents on financial performance indicators. The use of panel data is advantageous because it allows for the display of information and dynamic changes, as well as the identification of disparities between subjects, which is valuable in describing their behavior.

3.1 Variable selection and measurement

As a mandatory preliminary assessment, financial performance indicators based on accounting are indicated: return on assets (ROA), return on capital investment (ROIC), and the market capitalization. Accounting financial performance indicators, such as return on assets (ROA) and return on capital investment (ROIC), are widely used to evaluate firm performance (Lee, 2019). ROA, in particular, is frequently used to measure financial efficiency and performance (AlAli, 2020). ROA is a stable financial ratio over time compared to other financial ratios, making it a reliable measure of financial performance (Agbada, 2020; Vivian et al., 2022) used the market capitalization as a proxy for capital market performance and found that it was positively related to financial performance.

The independent variables were CO2 emissions and the patents for different types of green energy sources. Three types of green patents, specific to green energy sources, were selected:

Y02E10/00: Energy generation through renewable energy sources;
Y02E20/00: Combustion technologies with mitigation potential;
Y02E30/00: Energy generation of nuclear origin.

To ensure the accuracy of the results, it is necessary to control some important factors that affect the relationship between green patents and financial efficiency. These include company indicators: revenue, the ratio of capital expenditures (CAPEX) to the company's revenue, the ratio of R&D expenditures to revenue, return on equity (ROE), and country indicators (GDP *per capita*), which are added to track the effect of country in the international sample. Table 4 provides specific definitions of the variables.

3.2 Model setting

To assess the effects of CO2 emissions and the availability of mitigation and adaptation technologies, the logarithmic form of the variables is used in this study. It is helpful to avoid heteroscedasticity and linearity problems. Linear regressions were constructed with the following specifications:

$$\begin{aligned} ROA_{it} = \beta_0 + \beta_1 \times \ln CO2_{it} + \beta_2 \times \ln Y02E10_{it} + \beta_3 \times \ln Y02E20_{it} \\ + \beta_4 \times \ln Y02E30_{it} + \beta_5 \times lnRev_{it} + \beta_6 \times CAPEXRev_{it} \\ + \beta_7 \times R\&Dintensity_{it} + \beta_8 \times lnGDP_{it} + \varepsilon_{it} + u_i \end{aligned} \tag{1}$$

$$\begin{aligned} ROIC_{it} = \beta_0 + \beta_1 \times lnCO2_{it} + \beta_2 \times lnY02E10_{it} + \beta_3 \times lnY02E20_{it} \\ + \beta_4 \times \ln Y03E10_{it} + \beta_5 \times lnRev_{it} + \beta_6 \times CAPEXRev_{it} \\ + \beta_7 \times R\&Dintensity_{it} + \beta_8 lnGDP_{it} + \varepsilon_{it} + u_i \end{aligned} \tag{2}$$

$$\begin{aligned} lnMarCap_{it} = \beta_0 + \beta_1 \times lnCO2_{it} + \beta_2 \times lnY02E10_{it} \\ + \beta_3 \times \ln Y02E20_{it} + \beta_4 \times lnY03E10_{it} \\ + \beta_5 \times lnRev_{it} + \beta_6 \times CAPEXRev_{it} \\ + \beta_7 \times R\&Dintensity_{it} + \beta_8 \times ROE_{it} + \varepsilon_{it} + u_i \end{aligned} \tag{3}$$

where i signifies a firm or country and t the year (t = 1, 2, ., xxx), respectively. β_0 is a constant term and ε is the error term. lnMarCap represents the logarithm of market capitalization of company i in the year t lnCO2 represents the logarithm of CO2 emissions by country i in the year t ln Y02E10 represents the logarithm of the number of patents technologies of energy generation in country i by the year t ln Y02E20 p represents the logarithm of the number of patents combustion technologies with mitigation in country i by the year t ln Y02E30 represents the logarithm of the number of patents energy generation of nuclear origin in country i by the year t. lnGDP represents the logarithm of GDP *per capita* of the country of company i in the year t.

3.3 Sample selection and data collection

Despite the growth of renewable energy investment worldwide, research on patents registered in this field has its own specificities. Before 2011, Green Patent Innovation experienced a strong growth with an increase of 547% between 2002 and 2011. Since 2012, patents in this field have been steadily growing. According to FI CLAIMS patent services, patent applications in the field of Y02E (reduction of greenhouse gas emissions related to the generation, transmission or distribution of energy) reached their peak in 2019, and the number of registered applications and patents began to decrease. Therefore, we collected patent data from 2011 to 2020 to demonstrate the impact of upward trends in green energy innovation on the financial performance of companies.

In order to test our hypotheses, we have collected data on 72 largest companies of energy sector from Brazil, Russia, India, China, and South Africa from 2011 to 2020, including profitability rates (ROA, ROE, ROIC), market capitalization, revenue, capital expenditures (CAPEX), and R&D expenditures of these companies using S&P 500 Capital IQ database. We have also collected data on annual CO2 emissions of these countries from 2011 to 2020, using the International Energy Agency (IEA) database. We had to drop some companies from the initial sample due to the lack of data for some financial indicators. Thus, our final sample constituted 63 companies.

As we also aim to test the effects of accessibility of technologies for CO2 emissions' reduction, we collected data on patents for inventions in the energy sector. We used the Espacenet database developed by the European Patent Office to find information on technologies or applications for mitigation or adaptation against climate change (Y02 Cooperative Patent Classification). Significant share of patents registered in the database were the result of cooperative research by two or more companies and, as a result, it is difficult to identify each company's contribution to the creation of technology. Due to this factor, we decided to aggregate data on patents at country level to use in our models.

In the next section we describe the result of our analysis.

4 Results

4.1 Descriptive statistics of variables

Table 5 provides the descriptive statistics of the variables, showing that there are significant differences between the minimum and maximum of all variables, as expected. Therefore, there are sizable differences between various financial performance indicators.

In addition, a detailed examination of emissions and patent data reveals some country specifics. Picture 1 represents IEA data on CO2 emissions by country. Picture 1 demonstrates considerable growth of CO2 emissions in China (+24.6%) and India (+46.9%) accompanying higher GDP growth rates: nominal GDP of these countries increased from 2010 to 2020 by 93.5% and 64.88%, respectively. At the same time, Russia's nominal GDP at the same period increased only by 13.7%, while the GDP of Brazil and South Africa stagnated.

Total number of Y02 classification patents registered by companies and research centers from BRICS countries increased by more than 396%. Picture 2 represents data on patents registered by the end of 2011 (the beginning of the period analyzed), 2015 (the year of Paris Agreement adoption), and 2020 (the end of the period analyzed).

The data demonstrates absolute leadership of China among BRICS countries in terms of renewable energy technologies (94% of patents by 2020) and combustion technologies with mitigation

TABLE 5 Descriptive statistics of variables.

	Variable	Obs	Mean	SD	Min	Max	Prediction
Dependent variables	ROA_{it}	667	2,928	7,342	−79,669	21,104	-
	$ROIC_{it}$	667	4,955	7,766	−57.54	62,683	-
	$lnMarCap_{it}$	166	9,612	1,268	4,599	13,206	-
Independent variables	$CO2_{it}$	667	8,569	0,920	5,968	9,208	(−) for all dependent variables
	$Y02E10_{it}$	50	8,673	2,125	0	10,455	(+) for lnMarCap
	$Y02E20_{it}$	50	6,401	1,758	0	8,118	(+) for all dependent variables
	$Y02E30_{it}$	50	6,088	1,460	0	7,451	(+) for ROA, ROIC
							(−) for lnMarCap
Control variables	$lnRev_{it}$	667	16,543	2,217	6,118	21,807	(+)
	$CAPEXlev_{it}$	667	0,114	0,149	0	1,645	(+)
	$R\&Dintensity_{it}$	667	0,009	0,016	0	0,120	(+)
	ROE_{it}	667	8,010	39,925	−34,043	61,115	(+) for lnMarCap

potential (89% of patents by 2020). Although in the field of new technologies in nuclear energy sector Russia continues to compete with China, its share in overall number of sample's patents decreased from 45.2% in 2011 to 23.4% in 2020, while China almost doubled its share (from 36.6% to 68.4%).

4.2 Multiple regression analysis

Our regression analysis was initiated with the building of pooled OLS regressions. However, according to the results of Breusch-Pagan test, the random-effect GLS model was more preferable. However, according to the results of the Hausman test, estimators obtained using fixed-effect OLS regression were consistent. These estimations are presented in Table 6.

While analyzing our data using OLS technique, we found out that adding all three "patents" variables to the model leads to multicollinearity, and decided to build our regressions, including variables Y02E10, Y02E20 and Y02E30 separately. Finally, using White test and modified Wild statistics we detected heteroscedasticity leading to possible biases in our regressions' results.

Taking into account these restrictions, we decided to apply a feasible generalized least squares (FGLS) approach, as it allows us to build regressions taking into account heteroscedasticity and cross-sectional correlation. The results for ROA are presented in Table 7.

Further, we build similar regressions for ROIC, as we found that the estimations obtained by the OLS method also were biased due to heteroscedasticity and multicollinearity. The results are presented in Table 8.

We further check whether the availability of mitigation or adaptation technologies contributes to market capitalization of BRICS energy sector companies. The results are presented in Table 9. GDPpc variable has been omitted due to collinearity and has been replaced with ROE (with 1-year lag).

According to the results obtained using FGLS estimations, higher volume of CO2 emissions leads to lower ROA, ROIC and market capitalization of energy companies significant at the 5% level.

We also find out that higher availability of renewable energy technologies (Y02E10) does not contribute to ROA, but for ROIC they contribute significant at the 1% level.

Combustion technologies with mitigation potential (Y02E20) contribute to all financial performance: for ROA significant at the 10% level, and for ROIC and market capitalization significant at the 1% level.

Accessibility of nuclear energy technologies (Y02E30) contribute to ROA and ROIC significant at the 10% level.

We have not encountered any endogeneity problems in our econometric analysis of models with specifications 2) (ROIC as the dependent variable) and 3) (natural logarithm of market capitalization as the dependent variable). However, there are still some limitations to our analysis. Firstly, our sample size is relatively limited, consisting of 72 companies across five countries. Additionally, less than half of the sampled companies disclose information about their R&D expenditures, which could result in an unobserved effect of R&D intensity on corporate performance, despite this variable being included in our models' specifications.

4.3 Robustness check

We conducted an additional analysis in order to check the robustness of our results.

We checked our models for endogeneity, using the Durbin-Wu-Hausman test. While we have not detected this problem for the models with ROIC and natural logarithm of market capitalization as dependent variables, we have detected an endogeneity in the model with ROA as dependent variable. In order to address this issue, we apply a two-step dynamic system GMM estimation technique, extending the Arellano-Bond approach (Arellano, Bover, 1995). This approach applies the

TABLE 6 OLS regressions with fixed effects for ROA.

Variables	ROA	ROA	ROA
$CO2_{it}$	−79,6699** (0.033)	−76,9850** (0.027)	−73,5966** (0.024)
$Y02E10_{it}$	0,7945 (0.282)	-	-
$Y02E20_{it}$	-	1,1168 (0.217)	-
$Y02E30_{it}$	-	-	2,6907 (0.168)
$lnRev_{it}$	1,0345** (0.039)	1,0203** (0.038)	1,0138** (0.030)
$CAPEXlev_{it}$	5,5390*** (0.000)	5,5573*** (0.000)	5,5187*** (0.000)
	1-year lag	1-year lag	1-year lag
$R\&Dintensity_{it}$	−11,7731 (0.400)	−11,9037 (0.398)	−12,9859 (0.349)
	1-year lag	1-year lag	1-year lag
$GDPpc_{it}$	1,4518 (0.163)	3,1831 (0.588)	1,9998 (0.735)
Year-effect	yes	Yes	Yes
$CONST$	615,8721* (0.059)	614,1062* (0.053)	585,7565** (0.048)
Number of observations	593	593	593
Hausman test p-value	86,22 (0.0000)	49,30 (0.0000)	46,93 (0.0000)
Robust standard errors	Yes	Yes	Yes
R-squared	0.1614	0.1623	0.1901

Note: we represent p-values in parenthesis. We also indicate statistical significance of coefficients' estimations: *** for 1% significance, ** for 5% significance, * for 10% significance.

TABLE 7 FGLS regressions for ROA.

Variables	ROA	ROA	ROA
$CO2_{it}$	−1,8762** (0.028)	−2,2423** (0.009)	−2,7144** (0.001)
$Y02E10_{it}$	0,4086 (0.235)	-	-
$Y02E20_{it}$	-	0,6790* (0.094)	-
$Y02E30_{it}$	-	-	1,6492** (0.009)
$lnRev_{it}$	0,6900*** (0.000)	0,6965*** (0.000)	0,7065*** (0.000)
$CAPEXlev_{it}$	1,9189** (0.016)	1,9413** (0.015)	1,8949** (0.018)
	1-year lag	1-year lag	1-year lag
$R\&Dintensity_{it}$	−14,1738** (0.043)	−14,5567** (0.037)	−15,4637** (0.027)
	1-year lag	1-year lag	1-year lag
$GDPpc_{it}$	1,4518 (0.163)	1,1052 (0.265)	−1,0539 (0.512)
$CONST$	−9,8581 (0.417)	−4,5822 (0.701)	12,7673 (0.450)
Number of observations	592	592	592
Wald chi2 p-value	214,24 (0.0000)	211.,59 (0.0000)	249,79 (0.0000)

Note: we represent p-values in parenthesis. We also indicate statistical significance of coefficients' estimations: *** for 1% significance, ** for 5% significance, * for 10% significance.

lag of the dependent variable as part of explanatory variables to track dynamics across the firms over the observed period addressing the endogeneity issue. The results of our regressions using this technique are presented in Table 10.

In the next section, we discuss our results based on the evidence from previous research.

5 Discussion

Our regression analysis suggests that reducing carbon emissions and adopting green strategies can enhance financial performance. The results of our econometric analysis prove several of our hypotheses, see the summary in Table 11.

TABLE 8 FGLS regressions for ROIC.

Variables	ROIC	ROIC	ROIC
$CO2_{it}$	−7,1510*** (0.000)	−7,7699** (0.000)	−4,4996*** (0.000)
$Y02E10_{it}$	2,2318*** (0.000)	-	-
$Y02E20_{it}$	-	3,0029*** (0.000)	-
$Y02E30_{it}$	-	-	1,6438* (0.088)
$lnRev_{it}$	0,7627*** (0.000)	0,7571*** (0.000)	0,6847*** (0.000)
$CAPEXlev_{it}$	1,5537 (0.118)	1,6010* (0.096)	1,4451 (0.140)
	1-year lag	1-year lag	1-year lag
$R\&Dintensity_{it}$	−15,3175* (0.065)	−14,9032* (0.073)	−14,9514* (0.069)
	1-year lag	1-year lag	1-year lag
$GDPpc_{it}$	−0,3068 (0.860)	−1,4503 (0.265)	−0,8740 (0.733)
$CONST$	35,5125* (0.059)	50,9351* (0.012)	28,6732 (0.285)
Number of observations	592	592	592
Wald chi2 *p*-value	229.66 (0.0000)	236.65 (0.0000)	199.86 (0.0000)

Note: we represent *p*-values in parenthesis. We also indicate statistical significance of coefficients' estimations: *** for 1% significance, ** for 5% significance, * for 10% significance.

TABLE 9 FGLS regressions for Market capitalization.

Variables	MarCap	MarCap	MarCap	MarCap
$CO2_{it}$	0,6353 (0.700)	−2,1911 (0.392)	−46,4702 (0.136)	−7,0983** (0.007)
$Y02E10_{it}$	0,5396 (0.129)	-	-	−0,9338*** (0.000)
$Y02E20_{it}$	-	0,5107 (0.129)	-	1,3943*** (0.000)
$Y02E30_{it}$	-	-	10,2913 (0.129)	0,0038 (0.989)
$lnRev_{it}$	0,6551*** (0.000)	0,6551*** (0.000)	0,6551*** (0.000)	0,6551*** (0.000)
$CAPEXlev_{it}$	0,3331 (0.425)	0,3331 (0.425)	0,3331 (0.425)	0,3331 (0.425)
	1-year lag	1-year lag	1-year lag	1-year lag
$R\&Dintensity_{it}$	0,0103 (0.996)	0,0103 (0.996)	0,0103 (0.996)	0,0103 (0.996)
	1-year lag	1-year lag	1-year lag	1-year lag
ROE_{it}	0,0046* (0.052)	0,0046* (0.052)	0,0046* (0.052)	0,0046* (0.052)
	1-year lag	1-year lag	1-year lag	1-year lag
$CONST$	−13,0576 (0.397)	14,4640 (0.501)	49,6546 (0.139)	62,2111 (0.103)
Number of observations	151	151	151	151
Wald chi2 *p*-value	284.57 (0.0000)	284.57 (0.0000)	284.57 (0.0000)	284.57 (0.0000)

Note: we represent *p*-values in parenthesis. We also indicate statistical significance of coefficients' estimations: *** for 1% significance, ** for 5% significance, * for 10% significance.

According to the results, a higher volume of CO2 emissions leads to lower ROA, ROIC and the market capitalization of energy companies. These results are consistent with the hypothesized that higher CO2 emissions reduce the financial performance and the market capitalization of energy companies (Saka and Oshika, 2014; Gabrielle and Toly, 2019; Desai and Raval, 2022).

Overall, the results of our regression models suggest a positive impact of the different groups of patents included in the Y02E20 code on renewable energy production. This is consistent with the results of recent studies (Baloch et al., 2021; Zoaka et al., 2022; Issa and Hanaysha, 2023).

However, it should be noted that patent group Y02E10 has no effect on the return on assets of firms in BRICS countries. The expansion of the Y02E10 patent category from 2011 to 2020 has been the most rapid among all categories; however, it does not seem to have a direct impact on the ROA for firms located in BRICS countries. Although China holds most of these patents, the number

TABLE 10 Two-step dynamic system GMM model for ROA.

Variables	ROA	ROA	ROA
$ROA_{i,t-1}$	0,4009*** (0.000)	0,4020** (0.028)	0,3742*** (0.000)
$CO2_{it}$	2,9222 (0.210)	2,8089 (0.258)	−4,7405* (0.087)
$Y02E10_{it}$	−0,5223 (0.355)	-	-
$Y02E20_{it}$	-	−0,4809 (0.451)	-
$Y02E30_{it}$	-	-	6,2625** (0.048)
$lnRev_{it}$	3,8161** (0.009)	3,8499** (0.009)	3,3492*** (0.001)
$CAPEXlev_{it}$	2,8783 (0.291)	2,9538 (0.289)	1,5869 (0.409)
	1-year lag	1-year lag	1-year lag
$R\&Dintensity_{it}$	0,5059 (0.970)	0,9099 (0.946)	−10,7467 (0.551)
	1-year lag	1-year lag	1-year lag
$GDPpc_{it}$	2,3889 (0.742)	2,2473 (0.765)	−9,0852 (0.115)
$CONST$	−54,2358 (0.908)	−63,4797 (0.893)	513,669 (0.494)
Number of observations	593	593	593
Wald chi2 *p*-value	215.51 (0.0000)	300.81 (0.0000)	235.75 (0.0000)
Standard errors	robust	robust	robust
AR (1) *p*-value	−2,3099 (0.002)	−2,3119 (0.002)	−2,7199 (0.006)
AR (2) *p*-value	−0,8806 (0.3785)	−0,8707 (0.3839)	−0,7440 (0.4569)

Note: we represent *p*-values in parenthesis. We also indicate statistical significance of coefficients' estimations: *** for 1% significance, ** for 5% significance, * for 10% significance.

TABLE 11 Summary of results of testing hypotheses.

Variable	ROA		ROIC		Market capitalization	
	Predicted	Found	Predicted	Found	Predicted	Found
$CO2_{it}$	(−)	(−)*	(−)	(−)*	(−)	(−) Partly
$Y02E10_{it}$	(+)	Not found	(+)	(+)*	(+)	(−)*
$Y02E20_{it}$	(+)	(+)*	(+)	(+)*	(+)	(+)*
$Y02E30_{it}$	(+)	(+)*	(+)	(+)*	(+)	Not found

Note: * means that effect is statistically significant.
Picture 1. Dynamics of CO2 emissions by BRICS, countries (million tonnes).

of patents related to renewable energy has more than doubled over the past decade. Nevertheless, this increase in patent activity does not necessarily result in a corresponding increase in return on assets.

Investment in renewable energy projects and their accompanying patents usually entails long-term commitments. These technologies often require extensive development periods that can last for several years or even decades. As a result, their financial implications, such as the return on assets, may not be immediately apparent. To achieve favorable returns on investments, it is crucial for investors to adopt a long-term outlook.

Our research revealed that the adoption of renewable energy technology was limited by insufficient infrastructure and competition from traditional energy sources, leading to a slowdown in market expansion. Consequently, it is possible that the financial benefits associated with patents in this field are not immediately apparent. Moreover, the technical maturity and effectiveness of these patents should also be considered, as some renewable energy technologies are still in the early stages of commercialization. Although these technologies offer the potential for future profitability, their current efficiency and cost-effectiveness may not yet rival those of traditional energy sources, which could limit their short-term impact on a company's profitability.

Even though the above restrictions make things harder, it is important to see how patent groups like Y02E20 (which includes combustion technologies that could help reduce emissions) and Y02E30 (which includes nuclear energy technologies) can help the bottom lines of energy companies. These patent groups play a critical role in determining the ROA and ROIC of companies operating in the energy industry.

Combustion technologies with mitigation potential (Y02E20) have been developed to enhance fuel efficiency and reduce emissions. Among BRICS countries, China leads in this patent category, although the growth in registered patents is not as steep as that in the Y02E10 category. Improved fuel efficiency can result in decreased operational costs, potentially increasing net income and, consequently, ROA.

Government regulations from the BRICS countries, which compel businesses to allocate resources toward the adoption of emission-reducing technologies, are a major driving force behind the extensive development of Y02E20 technologies. This investment can assist companies in avoiding potential penalties, thereby preserving profits and improving ROA and ROIC.

Recognition should be given to the advancements in nuclear power technologies across all countries (Y02E30). The high energy density of nuclear power enables the production of a substantial amount of energy from a small amount of fuel. This efficiency can result in decreased fuel costs per unit of energy, thereby enhancing profitability and positively affecting ROA and ROIC.

Nuclear energy is a stable and low carbon source of energy and offers several advantages to energy firms. The stability of this energy source can result in predictable cash flows and improved returns on invested capital.

One of the key benefits of nuclear power plants is their long operational lifespan, which enables extended asset utilization. This can lead to a favorable ROA over time as assets continue to generate revenue.

Combustion and nuclear energy technologies, which have the potential for mitigation, come with a set of risks and challenges. These risks include high initial capital costs, lengthy development periods, regulatory barriers, and issues of public acceptance. These factors can have a significant impact on the financial performance and returns on the assets and equity of companies operating in the energy sector. Despite these challenges, both combustion and nuclear energy technologies offer opportunities for mitigation and have the potential to shape the future of energy production. Therefore, it is important to consider the risks and challenges associated with these technologies when making investment decisions in the energy sector.

Another observed trend is the impact of Y02E patents on the market capitalization of energy-sector companies in BRICS countries. Our regression analysis indicates a positive response of market capitalization to the growth of Y02E20 - efficient technologies. This finding suggests that investors view the development of these technologies as a positive indicator of a company's growth potential. Conversely, the lack of a significant influence of nuclear energy technologies on market capitalization in these countries implies that other factors may play a more substantial role in shaping market values.

Moreover, controlling variables such as company revenue, CAPEX to revenue ratio, R&D expenditures to revenue ratio, and return on equity also significantly explain the variations in market capitalization for energy sector companies in BRICS countries. The results underscore the significance of incorporating sustainable energy practices into business operations and the role of patents in promoting innovation and growth in the industry.

The relationship between the adoption of renewable energy sources and financial success is a prime example of how businesses prioritizing social and environmental responsibility in their operations can attain financial prosperity. Stakeholder theory argues that considering the concerns of all stakeholders, not just shareholders, in decision-making processes can result in both social and financial success.

6 Conclusion and policy recommendation

Technology innovation in many national economies across specific data distribution segments has been observed. Furthermore, it is important to note that the degree of asymmetries in the relationships between the variables varies among countries, emphasizing the significance of national legislatures reflecting the developments in green finance and renewable energy technologies.

Despite challenging business environments and uncertain economic prospects, the governments of the BRICS countries should prioritize the development and utilization of renewable energy technologies. According to the World Energy Outlook (WEO, 2023), clean technologies will remain at the forefront as 2030 approaches. It is crucial for government initiatives in the BRICS countries to continue accelerating the development of renewable energies. Developed countries' legislative initiatives can serve as a foundation for these efforts. For instance, the United States offers investment tax credits for energy storage, which encourages the development of energy storage technologies such as batteries and supports the growth of renewable energy. Additionally, the European Union has developed a Green Deal industrial plan, which outlines key initiatives to help the EU meet its 2030 renewable energy targets by focusing on energy conservation, clean energy production, and diversifying the EU's energy supply.

Our study provides empirical evidence that sheds light on the complex relationship between various independent variables, such as CO2 emissions, nuclear energy technologies, and patents related to renewable energy, and their effects on the market capitalization of energy sector companies in BRICS countries. Our findings contribute to a deeper understanding of the factors that impact market capitalisation in the energy sector and offer valuable insights for strategic decision-making and policy development. By examining the interplay between these variables, we aim to provide a comprehensive perspective on the factors that influence market capitalization in the energy sector in BRICS countries.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

EM: Conceptualization, Data curation, Methodology, Project administration, Resources, Writing–original draft. KP: Data curation, Formal Analysis, Funding acquisition, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing–review and editing. OT: Conceptualization, Data curation, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing–review and editing.

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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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