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Energy policy diversity and green bond issuance around the world

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ABSTRACT

The study utilizes new IMF data to explore the effect of energy policy diversity on the issuance of green bonds in seventy countries from 1991 to 2021. It develops a measure of energy production diversity that captures the variations in key alternative energy sources, enhancing our understanding of energy policies. The results reveal that countries with greater energy policy diversity are associated with higher green bond issuance growth, shedding light on the relationship between environmental considerations and sustainable finance. Environmental factors, such as higher energy demand, reduced greenhouse gas emissions, and decreased fossil fuel subsidies, are associated with greater green bond issuance. However, changes in energy policy diversity may not produce an immediate or linear impact on green bond issuance. The study reveals that nuclear power and solar power stand out as the principal catalysts driving growth within the green bond market, out of various energy sources. Nonetheless, countries that emphasize nuclear power generation might confront challenges in supporting green finance projects due to concerns regarding the integrity of water infrastructure. The insights derived from our research offer valuable guidance for both private sector enterprises and public sector endeavors involved in green financing initiatives. Additionally, our findings shed light on the impact of cultural factors on the financial behavior of nations.

1. Introduction

Green bonds are a key source of finance for sustainable investment. The green bond market has experienced significant growth in recent years as the demand for environmentally friendly investments has increased. In 2022, the global climate-related bond market had recorded a cumulative volume of USD3.7tn, of which USD858.5bn were new issues, of which 58% were green bond issues (Climate Bond Initiative, 2022). There has been a diversification of issuers in the green bond market, with an increasing number of companies and financial institutions issuing green bonds. The green bond market is expanding geographically, with issuers from emerging markets such as China and India accounting for a growing share of green bond issuance. Innovation in the green bond market increased, including new green bond products such as sustainability-linked bonds and transition bonds (Lee et al., 2023). Investor demand for green bonds continues to grow, with a growing number of institutional investors and asset managers incorporating environmental, social, and governance (ESG) considerations into their investment decisions. Although sharing characteristics as financial instruments, “green bonds” differ from regular bonds by their label, which indicates a dedication to utilizing the proceeds solely for the purpose of funding or refinancing projects, assets, or business activities that are environmentally sustainable (ICMA, 2015).

Energy and green finance are closely related, as green finance plays a crucial role in supporting the deployment of sustainable energy technologies (Sachs et al., 2019). Sustainable energy technologies, such as renewable energy sources like wind and solar power, are essential for reducing greenhouse gas emissions and mitigating the impacts of climate change. However, these technologies often require significant upfront investments, which have longer payback periods than traditional fossil fuel-based energy sources. This is where green finance could help, by providing the necessary financing and investment to support the development and deployment of these technologies. Green finance could take many forms, including green bonds, green loans, carbon credits, sustainable energy funds, and green mortgages, among others. These financial instruments are specifically designed to support environmentally friendly projects and technologies, including sustainable energy projects (Luc et al., 2021). For example, green bonds could be used to finance the construction of a new wind farm, while green loans could be used to finance the installation of solar panels on a commercial building. Carbon credits could be used to fund the development of renewable energy projects that reduce greenhouse gas emissions, while

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sustainable energy funds could provide investors with exposure to a diversified portfolio of sustainable energy projects.

More broadly, energy policies could have a significant impact on the growth of the green bond market. For example, many governments have set renewable energy targets to reduce their reliance on fossil fuels and combat climate change (IEA, 2022a). These targets could create a market for renewable energy projects and provide a clear signal to investors that there will be demand for green bonds in the future. Moreover, the establishment of feed-in tariffs could incentivize the development of renewable energy by providing a guaranteed price for electricity generated from renewable sources (Pembina Institute, 2021). This could reduce the risk for investors and make it easier for renewable energy projects to secure financing through the issuance of green bonds. Furthermore, carbon pricing policies, such as carbon taxes or cap-and-trade systems, could create a financial incentive for companies to reduce their carbon emissions (Parry, 2021). This could encourage the development of renewable energy and other low-carbon technologies and provide a source of revenue for governments that could be used to support the issuance of green bonds. In addition, policies that establish energy efficiency standards for buildings, appliances, and vehicles could create demand for green bonds to finance projects that meet these standards (Rasoulinezhad and Taghizadeh-Hesary, 2022). This could include investments in energy-efficient lighting, heating and cooling systems, and insulation. Likewise, the growth of the green bond market could be facilitated by the adoption of green procurement policies by governments and other major organizations. These policies would prioritize the procurement of goods and services with minimal environmental impact, thereby generating demand for green bonds to finance projects that meet these criteria. However, the relationship between energy policies and green bond issuance has been inadequately explored.

Specifically, energy production diversity plays a key role in green finance (Quian, 2022). The utilization of a wide range of energy sources and technologies to generate electricity and meet energy needs requires suitable financing, which green bonds could provide as they are specifically designed to fund environmentally friendly and sustainable projects. Energy production diversity is a crucial factor in the context of green bond issuance because it supports risk management, resilience to climate change, the transition to renewable energy, balanced energy supply, innovation, stakeholder engagement, and long-term sustainability goals (Zhang and Yang, 2016). These factors collectively enhance the credibility and effectiveness of green bond-funded projects in promoting environmentally friendly and sustainable practices. In essence, the association between energy production and green finance revolves around driving a transition towards cleaner and more sustainable energy sources, mitigating environmental impacts, reducing emissions, fostering innovation, and aligning financial investments with environmental and social objectives. This partnership is vital for achieving a sustainable and resilient energy future.

This paper aims to contribute to the existing literature by examining the impact of energy policies on the issuance and development of green bonds in various countries. Green bonds differ from traditional debt instruments in that their issuance is dependent on environmental factors, which may be influenced by energy policies. Additionally, the fact that the proceeds from green bonds are dedicated to environmentally friendly investments implies that their issuance may be influenced by energy policies and other sustainability considerations. By exploring these relationships, the study addresses some of the gaps in the current literature. It investigates the relationship between energy production diversity and the value of green bond issuance in seventy countries from 1991 to 2021 using recently released country-level data by the International Monetary Fund (IMF). Our analysis utilizes a measure of energy production diversity, which is derived from the first principal component of eight distinct energy sources for each country and year. Additionally, the study accounts for the influence of environmental, macroeconomic, and institutional factors. To address the potential concern of endogeneity in energy production policies, the study employs instrumental variable regression models, using the political commitment to sustainability index as an external instrument. Furthermore, the study employs Oster's (2019) coefficient stability test, a novel approach, to mitigate the potential biases. The outcomes of our analysis indicate a positive association between higher energy production diversity and increased value of green bond issuance. These findings withstand robustness checks involving alternative variable measures, sample structures, and model specifications. It becomes evident that energy policies indeed play a role in fostering the growth of the green bond market. To delve deeper into the contributions of different energy sources, the study conducts dominance analysis, which intriguingly highlights nuclear power generation as the dominant energy contributor to the growth of the green bond market.

Our study represents the first formal attempt to investigate the influence of energy production diversity policies on green bond issuance, filling a gap in the existing literature on the association between energy policy and green finance. This research contributes to the field in several ways. Firstly, the study develops a measure of energy production diversity that captures the variations in key alternative energy sources, enhancing our understanding of energy governance policies (Mayumi and Giampietro, 2006; Costantini and Crespi, 2021). Secondly, the results provide robust evidence of the impact of energy production policies on green bond issuance at the country level, shedding light on the role of energy factors in the relationship between environmental considerations and sustainable finance (Sachs et al., 2019). Thirdly, our study covers an extended sample period and a wide cross-section of countries, capturing green finance trends, economic cycles, and potential long-term effects across various jurisdictions (Mertzanis and Tebourbi, 2023; Mertzanis, 2021). The analysis mitigates potential biases arising from omitted variables by controlling for environmental, economic, and institutional factors. Additionally, the study examines the total value of green bond finance, allowing us to analyze both private and public sector initiatives in green financing and investigate the influence of cultural factors on national financing behavior. Furthermore, the study conducts a separate analysis of the effects of corporate green bond financing.

The paper is structured as follows: Section 2 provides an overview of the existing literature on energy and the development of the green bond market. Section 3 presents detailed information on the data and the empirical methodology employed in our analysis. The findings of the baseline analysis are presented in Section 4. Section 5 conducts sensitivity tests, while Section 6 focuses on the analysis of endogeneity. Additional robustness checks are presented in Section 7. Finally, Section 8 concludes the paper, summarizing the key findings and implications.

2. Related literature

2.1. Environmental concerns and green bonds

Recognizing the urgent need to combat global warming and environmental deterioration, the shift towards a low-carbon global economy has been widely acknowledged. However, this transition necessitates not only political determination but also substantial public and private investments (The United Nations, 2020). According to the Green Finance Synthesis Report published by the Group of Twenty (G20), an estimated USD90 trillion would be required over the next 15 years to attain global sustainable development goals (Green Finance Study Group, 2016). Nevertheless, the implementation of most green investment projects is costly (Baulkaran, 2019), carrying higher risks and potentially lower returns (Chiesa and Barua, 2019; Quatrini, 2021), underscoring the importance of establishing new sources of financing and suitable mechanisms for green investments. Green bonds are a key source of finance for sustainable investment.

European countries were the first to venture into green bond issuance during the 1990s (IMF Climate database). However, it was not until the notable issuance by the European Investment Bank in 2007, followed by the World Bank in 2008, that the green bonds market began to experience growth. Since then, the market has rapidly expanded, particularly after 2011, with a cumulative value surpassing USD 260 billion worldwide and an average value of approximately USD 5.2 billion per issuance (CBI, 2019). The adoption of the Paris Agreement in 2015 has played a significant role in fueling the growth of the green bond market, as signatory countries have been spurred into action. Furthermore, the European Commission's European Green Deal policy, established in 2019, aims to transform the European Union into a sustainable economy and society by aligning stakeholders with sustainability-driven incentives. Achieving the goals of the green economy will necessitate international cooperation and partnerships to mobilize both public and private funds. To mitigate the risks of greenwashing and bolster investor confidence, thereby fostering the growth of the green bond market, the European Commission introduced a voluntary Green Bond Standard and an environmentally sustainable activity taxonomy in 2021, enhancing transparency and harmonization within the market (Badenhoop, 2022). Other policy measures that have contributed to the advancement of the green bond market include global enhancements in the transparency and disclosure requirements for securities issuance, incorporating climate and environmental information provided by issuers. Nevertheless, despite its impressive growth, the green bond market is still in its early developmental stage, and the average value of issuances remains relatively small compared to the conventional bond market.

2.2. Dynamics of the green bond markets

There are several environmentally related factors that could affect the growth of the green bond market. From the investor's side, the increasing demand for environmentally sustainable investments is a key factor (Eyraud et al., 2013; Heinkel et al., 2001). As more investors look for ways to invest in environmentally sustainable projects, the demand for green bonds is likely to increase. Investors are becoming more aware of the impact of climate change on the environment and are seeking investment opportunities that align with their values. Another related factor is the strong investor appetite for green bonds (*The International Finance Corporation (IFC),* 2019). Investors who are interested in sustainable investments may have a strong appetite for green bonds, which could create a positive feedback loop. As more green bonds are issued and perform well, this could further drive demand from investors. Another factor is favorable regulatory environment (OECD, 2020). Governments could encourage the growth of the green bond market by creating favorable policies and regulatory frameworks. For example, some governments may offer tax incentives or subsidies for green bond issuers or require certain levels of disclosure and reporting on environmental impacts. From the issuer's side, higher issuer interest in sustainable finance could lead to higher green bond issuance (Kaminker, 2017). As more issuers become interested in sustainable finance, the number of green bonds being issued is likely to increase. Issuers may see benefits in terms of reputation and access to capital by aligning their financing with environmental goals. Further, the growth of the green bond mark*et al*so depends on the availability of suitable markets and projects to finance (Bloomberg, 2015; Zhang et al., 2019). If there are not enough high-quality, environmentally sustainable projects that could be financed with green bonds, the market may not grow as quickly.

2.3. Energy production policies and green bond markets

Energy production policies exhibit significant variation across nations, driven by a confluence of diverse factors (Marques et al., 2010; Kim and Park, 2016). Disparities in the accessibility of distinct energy resources underpin the shaping of energy policies, reflecting the abundance or scarcity of these resources. Furthermore, distinct priorities emerge as certain countries place paramount importance on curtailing greenhouse gas emissions and addressing climate change. Consequently, their emphasis lies in expanding renewable energy outlets and diminishing dependence on conventional fossil fuels. Conversely, others prioritize economic advancement and energy security, leading them to chart dissimilar policy trajectories. Additionally, nations with substantial energy import dependence prioritize the diversification of energy sources to fortify their energy security (Kruyt et al., 2009). Technological sophistication also casts a pivotal influence, shaping a nation's capacity to harness specific energy sources (Löschel, 2002). Notably, advanced solar technology prompts an emphasis on solar energy, while robust wind technology directs attention to wind power. Economic considerations, encompassing energy pricing dynamics and employment generation, wield significant sway. They influence the extent to which energy subsidies are extended. Regulatory frameworks and international commitments further contribute to the intricate tapestry of energy policies. Varied levels of governmental intervention span the energy market spectrum, ranging from closely managed markets with centralized planning to those determined by market dynamics. Global agreements like the Paris Agreement on climate change steer policy alignment, prompting nations to tailor energy strategies congruent with emission reduction goals and the adoption of clean energy. Geopolitical dimensions also factor in, particularly for energy-exporting countries, where energy resources serve as tools for diplomatic maneuvering and economic influence (Palle, 2021). Cultural beliefs and societal values hold substantial weight, with differing outlooks influencing policy directions (West et al., 2010). For instance, nations propelled by robust environmental movements champion clean energy, while those rooted in nuclear technology traditions may embrace nuclear energy favorably. Public sentiment, including apprehensions surrounding health and environmental ramifications, exerts its sway on policy contours. Stakeholder interactions with industries, environmental factions, and communities collectively shape policy formulations. In summation, the intricate interplay of these multifaceted factors renders energy production policies distinct across the global landscape.

Energy-related factors influence directly and indirectly green bond issuance. First, investor demand for sustainable energy projects is a key determinant of green bond issuance (Talan and Sharma, 2019; Taghizadeh-Hesary and Yoshino, 2019; Prajapati et al., 2021a, 2021b). As more investors seek to invest in sustainable investments, the demand for green bonds grows. The impact of energy production on investor demand could vary depending on several factors, including the type of energy being used, the industry in question, and the investor's specific priorities and goals. In general, investors may be more attracted to companies and industries that prioritize sustainable and environmentally friendly practices. This is because such practices could help reduce risk and improve long-term profitability by reducing costs associated with resource consumption and waste management, as well as attracting consumers who are increasingly concerned about environmental issues. On the other hand, companies and industries that rely heavily on non-renewable energy sources, such as coal or oil, may face increasing scrutiny and reduced demand from investors as concerns about climate change and environmental sustainability continue to grow. In addition to environmental considerations, investors may also be influenced by other factors related to energy use, such as government policies and regulations, the availability of alternative energy sources, and technological advancements in energy efficiency and conservation.

Second, the cost of capital for green projects could be higher than for traditional projects. Issuers may issue green bonds to take advantage of lower borrowing costs, which could make sustainable investments more economically viable (Presbitero et al., 2016; IEA, 2021; Ameli et al., 2021; Gianfrate et al., 2021). The impact of energy production on the cost of capital could depend on several factors, including the type of energy being produced, the country or region in question, and the prevailing market conditions. In general, the cost of capital for energy production projects could be affected by a range of factors related to the underlying technology, regulatory environment, and economic conditions. For example, projects that rely on older, more established technologies may be viewed as less risky and therefore may have a lower cost of capital, while projects that use newer, more innovative technologies may be seen as riskier and have a higher cost of capital. The cost of capital for energy production could also be affected by government policies and incentives. For example, government subsidies or tax credits for renewable energy sources may make projects using these technologies more attractive to investors, which could help lower the cost of capital. In addition, market conditions such as interest rates and investor sentiment could also impact the cost of capital for energy production. In times of economic uncertainty, for example, investors may demand a higher return on their investments, which could increase the cost of capital for energy production projects. Overall, the impact of energy production on the cost of capital could be complex and multifaceted and could depend on a range of factors related to the specific project, industry, and broader economic and regulatory environment. However, as sustainability concerns and renewable energy technologies continue to gain momentum, investment projects that prioritize energy efficiency and renewable energy sources are likely to become increasingly attractive to investors, potentially helping to lower the cost of capital over time.

Third, government policies that incentivize or require companies to invest in sustainable projects could also drive green bond issuance (OECD, 2015; 2020; IMF, 2021). For example, regulations that require companies to reduce their carbon footprint could encourage them to issue green bonds to finance renewable energy projects. Energy production could have a significant impact on environmental policies and regulations, both in terms of shaping the development of new policies and regulations, and in terms of influencing the implementation and enforcement of existing ones. One of the primary ways that energy production affects environmental policies and regulations is through its contribution to greenhouse gas emissions and climate change. As concerns about climate change have grown in recent years, governments around the world have implemented a range of policies and regulations aimed at reducing greenhouse gas emissions and promoting the transition to cleaner, more sustainable energy sources. Energy production companies are often directly impacted by these policies and regulations, as they are required to comply with emissions standards and other environmental regulations. Energy production could also influence environmental policies and regulations through the lobbying and advocacy efforts of industry groups and individual companies. These groups and companies may seek to influence policymakers and regulatory agencies to adopt policies and regulations that are more favorable to their interests, such as relaxing emissions standards or providing subsidies for certain types of energy production. At the same time, energy production could also be shaped by environmental policies and regulations, as companies seek to comply with existing regulations or take advantage of incentives for cleaner and more sustainable energy production. For example, policies and regulations that promote the use of renewable energy sources such as wind and solar power could create opportunities for companies to develop innovative technologies and business models in these areas. Overall, the relationship between energy production and environmental policies and regulations is complex and multifaceted, with both sides influencing and shaping the other over time. As concerns about climate change and environmental sustainability continue to grow, it is likely that the role of energy production in shaping environmental policies and regulations will become increasingly important.

Fourth, concerns over their reputation and branding could also drive issuers to issue green bonds (Cheng et al., 2022; Bachelet et al., 2019; Hockerts, 2015; Hale and Santos, 2008). Green bonds could signal to investors and customers that the issuer is committed to sustainability, which could help to improve their brand image. Energy production could have a significant impact on corporate reputation and branding, as public perception of a company's environmental and social responsibility could be strongly influenced by its energy production practices. Companies that are perceived as being environmentally responsible and committed to sustainable practices may be more attractive to consumers, investors, and other stakeholders. This could enhance their brand reputation and help differentiate them from competitors, potentially leading to increased customer loyalty and higher sales. On the other hand, companies that are seen as having a negative impact on the environment or contributing to climate change through their energy production practices may face reputational risks, including public scrutiny and negative media coverage. This could damage their brand reputation and lead to reduced customer loyalty, as well as potential legal and regulatory challenges. In addition, corporate reputation and branding could be influenced by a range of factors related to energy production, including the use of renewable energy sources, energy efficiency measures, and investments in sustainable technologies and practices. Companies that are seen as leaders in these areas may be viewed more positively by stakeholders, potentially enhancing their reputation and branding. Overall, the impact of energy production on corporate reputation and branding is significant and could play a key role in shaping public perception of a company's environmental and social responsibility. Companies that prioritize sustainable and responsible energy production practices are likely to be viewed more positively by stakeholders, potentially leading to a range of benefits for the company and its brand reputation.

Fifth, market conditions, such as inflation rates and investor sentiment, could also impact green bond issuance, especially in times of economic uncertainty (Alexopoulou et al., 2010; Arfaoui et al., 2023). One way that energy production could impact green bond issuance is through its effect on inflation. Energy production is a major component of the overall economy, and changes in energy prices could have a significant impact on overall inflation levels. Higher energy prices could lead to higher inflation, which may cause central banks to raise interest rates to control inflation and maintain price stability. Energy production could also affect economic growth, which could in turn impact market sentiment. For example, investments in renewable energy and energy efficiency technologies could create new job opportunities and stimulate economic growth, potentially leading to higher investor demand and more positive market sentiment. On the other hand, disruptions in energy production or higher energy prices could lead to reduced economic growth and lower investor demand, potentially leading to more negative market sentiment. In addition, energy production could be influenced by government policies and incentives, which could also impact interest rates and market sentiment. For example, government subsidies or tax credits for renewable energy sources may make projects using these technologies more attractive to investors, potentially leading to higher investor demand and more positive market sentiment. Conversely, changes in government policies or regulations that impact the energy sector could lead to lower investor demand and more negative market sentiment. Overall, the impact of energy production on interest rates and market sentiment could be complex and multifaceted and could depend on a range of factors related to the specific project, industry, and broader economic and regulatory environment. However, energy production is a vital component of the overall economy and could have a significant impact on interest rates and market sentiment over time.

Sixth, energy production could have a significant impact on the demand for environmental protection, as it is a major source of greenhouse gas emissions and other environmental pollutants (Myre and Aksic, 2022; Fridgen et al., 2020; Chan et al., 2017). In general, the production and consumption of traditional fossil fuels such as coal, oil, and natural gas are associated with a range of environmental impacts, including air and water pollution, deforestation, and climate change. This has led to growing concerns among policymakers, businesses, and consumers about the need to transition to more sustainable and environmentally friendly forms of energy production. As a result, there has been increasing demand for environmental protection measures and insurance policies aimed at reducing the environmental impact of energy production. These may include measures such as renewable energy standards, carbon pricing, and emissions regulations, which are designed to encourage the use of cleaner and more sustainable energy sources and reduce the environmental impact of energy production. In addition to government policies and regulations, consumer and business demand for environmentally friendly energy production could also play a key role in driving the adoption of sustainable energy technologies. As consumers and businesses become more aware of the environmental impacts of their energy use, there is growing interest in energy efficiency measures, renewable energy sources, and other environmentally friendly technologies. Overall, energy production could have a significant impact on the demand for environmental protection, as it is a major source of environmental pollution and climate change. As concerns about the environment continue to grow, there is likely to be increasing demand for sustainable and environmentally friendly forms of energy production, as well as policies and regulations aimed at reducing the environmental impact of energy production.

2.4. Energy policies and green finance – adverse effects

Energy production policies can also act as deterrents to green finance. For instance, when energy policies don't place a premium on environmental sustainability, they may signal a lack of sustained commitment to eco-friendly initiatives (Howells and Roehrl, 2012). Investors inclined towards projects that align with sustainable objectives could interpret such policies as incongruent with their investment preferences. Moreover, policies that favor or heavily subsidize traditional energy sources like coal or oil can disadvantage green energy ventures. Investors might interpret the lack of governmental backing for renewable energy as an indicator of heightened risk, diminishing their inclination to invest in green bonds associated with these projects (Davis, 2014; Monasterolo and Raberto, 2019). Furthermore, the fluctuation or inconsistency of energy policies can inject uncertainty into the green energy sector for investors. Frequent shifts or reversals in policies can erode investor confidence and deter them from channeling resources into green projects through bonds (Ehlers et al., 2020). Similarly, onerous regulations or intricate permitting procedures specific to renewable energy undertakings might escalate costs and protract project implementation timelines. This extension of revenue generation timelines renders green projects comparatively less appealing to bond investors seeking relatively swifter investment returns. Challenges faced by renewable energy projects in terms of integrating into existing energy grids due to policy or technical impediments can hinder their ability to deliver consistent yields. This unpredictability renders these projects less enticing for investors and thus dampens the propensity to issue green bonds. Additionally, energy policies that encounter public opposition or lack popular endorsement can trigger delays, legal disputes, or even project abandonment (Peng et al., 2018). The resulting uncertainty becomes a deterrent for investors considering commitment to green bonds linked to such ventures. Manipulation of energy prices through policies that artificially depress or escalate them can distort market cues, thereby influencing the economic viability of green energy endeavors (Gallo, 2015). This distortion cascades to impact the allure of green bonds associated with these initiatives. Compounded by inadequate disclosure of the environmental repercussions and risks tied to conventional energy sources, investors may find it arduous to accurately assess the true hazards of these investments. This dearth of transparency can hinder responsible investment, including participation in green bonds. Thus, energy production policies that misalign with sustainability targets, lack coherence, or fall short in providing requisite support can foster an environment where green energy projects face hurdles in gaining traction. Consequently, the issuance of green bonds might be impeded as investors potentially view these projects as being less financially feasible or carrying heightened risks.

From another perspective, energy policies also exert influence on green finance through their impact on cryptocurrency activity. Cryptocurrency mining, a core procedure for upholding and validating transactions on blockchain networks, frequently demands substantial energy resources (Arfaoui et al., 2023). The sway of energy policies, which can shape electricity costs and accessibility, extends directly to the profitability of mining endeavors. Miners might opt to relocate operations to regions with more advantageous energy regulations to optimize their gains. However, select nations have imposed regulatory limitations on cryptocurrency mining owing to apprehensions about its ecological implications. Heightened energy usage and the carbon footprint linked to mining have prompted specific governments to curtail or proscribe mining undertakings. Policies that foster the adoption of renewable energy sources can mold the environmental sustainability of cryptocurrency mining. Some mining operations are progressively embracing renewable energy to counterbalance their ecological influence.

In a reciprocal manner, cryptocurrency activity possesses the potential to impact green bond issuance, albeit indirectly and within an intricate framework. Green bonds represent financial instruments custom-crafted to bankroll ecologically sustainable projects and initiatives. The interrelation between cryptocurrency activity and green bond issuance lies in their joint capacity to sway investor sentiment, market dynamics, and funding preferences (Yadav et al., 2022; Farid et al., 2023). Cryptocurrency markets often carry associations with volatility and speculative tendencies. Instances of notable fraud, security breaches, or regulatory uncertainties within the cryptocurrency sphere can precipitate a decline in investor trust not only in cryptocurrencies themselves but also in innovative financial tools like green bonds. Moreover, heightened market attention and media focus on cryptocurrency price oscillations, particularly during swift bullish or bearish trends, could divert the concentration of investors from sustainable investments such as green bonds (Piñeiro-Chousa et al., 2021). This could potentially impact the demand for and issuance of green bonds, particularly if potential investors find themselves engrossed in cryptocurrency-linked developments. Furthermore, the volatility and speculative character inherent in cryptocurrencies could foster a perception of high-risk markets. Investors, particularly those of an institutional and risk-averse disposition, might construe these markets as excessively uncertain. Such a perception could result in reduced allotments of funds to alternative investment avenues, including green bonds. Notably, investors engaged in green bonds typically adopt a long-term outlook, seeking stable returns from sustainable undertakings.

2.5. Research hypothesis

Drawing on the literature reviewed above, the study formulates the primary research hypothesis that greater diversity in energy production policies is associated with higher issuance values of green bonds. Specifically, the study measures energy production policy using a composite diversity index derived from eight diverse sources of energy through dimensionality reduction that reflects government decisions regarding energy production. Our study uses data from seventy countries over the period 1991–2021, while controlling for the influence of various economic, environmental, and institutional factors.

3. Data and identification strategy

3.1. Data

To establish a causal relationship between energy production diversity and green bond issuance, the study employs cross-sectional data spanning multiple years. The analysis focuses on a unique panel dataset comprising 351 public green bond issues, valued in USD billions, from seventy countries during the period of 1991–2021. Notably, most of these issues occurred after 2011, coinciding with the introduction of the Green Bond Principles by global investment banks. These principles established standardized procedures and requirements, thereby enhancing market confidence in this emerging financial instrument

(Cheong and Choi, 2020). Furthermore, the Principles for Responsible Investment (PRI), supported by the United Nations, has garnered over 1700 signatories from more than fifty countries, leading to an increase in the literature on green bond issuance and trading. Our sample primarily comprises corporate green bonds, with sovereign green bonds accounting for approximately 9.5% of the total issuance value. The IMF climate database provides the most comprehensive collection of green bond data, while the Climate Bond Initiative database covers a narrower timeframe and fewer issues. The analysis combines green bond data with energy data from multiple sources, capturing energy policies and other pertinent environmental, economic, and institutional factors. The final baseline dataset consists of 349 green bond issues from eighty-four countries. To address potential outlier effects, the analysis utilizes the logarithmic values of the level variables.

3.2. Variables

Our study focuses on the value of green bonds issued by each country, denoted as GRNBND, as our primary outcome variable. Table 1 provides an overview of the average values of green bonds across all countries in our sample. The global average value of green bonds in our study stood at USD 5.1 billion, which, although lower than the average issuance value of conventional bonds, remains significant. Leading the pack in green bond issuance is China, with a value of USD 29.91 billion, followed by France (USD 24.02 billion) and the Netherlands (USD 16.96 billion). The middle range includes countries such as Costa Rica (USD 1.00 billion), the Czech Republic (USD 0.96 billion), and Taiwan (USD 0.93 billion). On the lower end of the spectrum, we find countries like Namibia (USD 0.009 billion), Seychelles (USD 0.03 billion), and Morocco (USD 0.01 billion). It is noteworthy that, in addition to China, European countries have been actively engaged in green bond issuance. Moreover, smaller, and lower-income countries have also entered the market, driven by growth opportunities despite facing barriers on both the demand and supply sides (Nguyen et al., 2021).

Table 1
Energy policies and green bond issuance (average country values).

Country	Green bond issuance	Energy policy diversity	Country	Green bond issuance	Energy policy diversity
Argentina	0.68	−0.73	Malaysia	0.29	−0.87
Australia	2.03	−0.83	Mauritius	2.48	0.56
Austria	1.42	−0.75	Mexico	2.30	−0.62
Bangladesh	0.35	−0.43	Morocco	0.01	−0.51
Belgium	5.83	−0.78	Namibia	0.00	−0.87
Brazil	0.87	−0.82	Netherlands	16.96	−0.75
British Virgin Isl	1.77	1.71	New Zealand	0.34	−0.85
Canada	5.47	−0.87	Nigeria	0.08	−0.88
Cayman Islands	3.54	1.67	Norway	2.96	−0.88
China	29.91	−0.88	Pakistan	0.50	−0.59
Colombia	0.30	−0.73	Panama	0.20	−0.31
Costa Rica	1.00	−0.80	Peru	0.48	−0.67
Czech Rep.	0.96	−0.86	Philippines	0.45	−0.41
Denmark	4.14	−0.80	Poland	2.46	−0.81
Egypt	3.00	−0.58	Portugal	1.78	−0.81
Estonia	0.07	1.30	Romania	0.48	−0.85
Fiji	0.09	0.13	Russia	0.79	−0.87
Finland	2.10	−0.73	Serbia	4.53	−0.85
France	24.02	−0.84	Seychelles	0.03	1.66
Georgia	0.75	−0.88	Singapore	2.18	−0.81
Germany	12.94	−0.79	Slovak Rep.	0.45	−0.79
Greece	0.78	−0.62	Slovenia	0.08	−0.88
Hong Kong	7.36	−0.88	South Africa	0.12	−0.87
Hungary	2.71	−0.86	Spain	7.44	−0.74
Iceland	0.88	−0.88	Sweden	7.76	−0.85
India	2.16	−0.88	Switzerland	0.75	−0.75
Indonesia	2.04	−0.78	Taiwan	0.93	−0.82
Ireland	4.88	−0.64	Thailand	0.61	−0.88
Israel	1.00	−0.88	Turkey	0.70	−0.87
Italy	6.22	−0.57	Ukraine	1.65	−0.86
Japan	5.45	−0.71	United Arab Emir	0.45	−0.88
Korea, Rep.	6.66	−0.83	United Kingdom	9.25	−0.83
Latvia	0.08	−0.88	United States	15.15	−0.86
Lithuania	0.42	−0.70	Vietnam	0.18	−0.87
Luxembourg	3.46	−0.72			
Macao	0.84	−0.88	Total	5.10	−0.65

Our primary predictor variable is a composite measure of energy policy diversity (ENRGPOL) which encompasses the shares of eight distinct sources: oil, coal, gas, biofuels, hydropower, solar, wind, biofuels, and nuclear power. The World Development Indicators provide the data. Energy policy diversity is concerned with the types of energy sources used for energy production as these have a significant impact on public health, the economy, and the environment. To construct the composite variable, the study uses a robust principal-component-analysis (PCA) to derive dimensionality reduction scores. The robust PCA method is advantageous because it can handle outliers in the data and corrupted observations (Candes et al., 2009). We began by using the shares of energy production per country and year that come from each of the eight sources. We then normalized the data to ensure that each variable was on the same scale and had equal weight in the analysis. Next, we calculated the covariance matrix of the standardized dataset and obtained the eigenvalues. The first principal component explained 78.2% of the variability of the constituent variables. We subsequently calculated the loadings of each variable on each principal component to capture the correlation between the original variables and the principal components and used them to generate the principal component scores. We used the first principal component as our primary predictor variable since it captured the largest amount of variability of the eight different energy sources. Given that the composition of energy production is a primary policy objective of governments, our variable could effectively approximate the different energy policy diversity implemented in a country.

Our objective is to examine the connection between shifts in energy production diversity and green finance. Real-world scenarios often involve additional variables that impact green finance, potentially distorting or fragmenting the comprehension of the core cause-and-effect relationship. To address this, we introduce control variables that allow us to dissect and grasp the intricate interplay between energy production diversity and green finance. These variables are as follows: The first control variable is the (log) total volume of energy demand, measured in terawatt-hours (ENRGDEM), which is obtained from the BP Statistical Review of World Energy report. Energy demand plays a critical role in the issuance of green financial instruments since their primary objective is to finance projects and initiatives that promote environmental sustainability and address climate change (Sorrell, 2015; Arif et al., 2015; Yan et al., 2023). The need to transition to a low-carbon economy is a primary driver of green bond issuance as energy demand is a significant contributor to greenhouse gas emissions. Higher levels of energy demand could increase the demand for investment in renewable energy projects and energy efficiency initiatives, which are key areas of focus for green bonds. We anticipate a positive relationship between higher energy demand and green bond issuance.

The second control variable is the (log) volume of greenhouse gas emissions released during energy production (GASEMIS), which is provided by the IMF Climate Database. The levels of emissions could exert a substantial impact on the issuance of green bonds, given that the reduction of emissions is a key objective within the green bond market (OECD, 2020; Ehlers et al., 2020). On the one hand, the emissions contribute to climate change, and green bonds are intended to fund projects that decrease those emissions and address climate change's consequences. On the other hand, the impact of greenhouse gas emissions on the issuance of green bonds could be more complex. For example, specific industries or sectors, such as oil and gas, might find it challenging to access green financing due to their operations' nature, while developing countries could encounter difficulties in obtaining financing for sustainable development due to their high emission levels. We anticipate a negative relationship between higher greenhouse gas emissions and green bond issuance.

The third control variable is the amount of fossil fuel subsidies for energy production (FOSSSUB) measured in USD. The data for this variable is provided by the IMF Climate Database. The impact of fossil fuel subsidies on the issuance of green bonds could be both direct and indirect (Davis, 2014; Monasterolo and Raberto, 2019). Directly, these subsidies could create distortions in the market by providing financial support to non-renewable energy sources, which could make it harder for renewable energy projects to compete. Consequently, green projects may find it challenging to secure funding through green bonds as they may not be able to offer returns that are competitive compared to non-green alternatives. This, in turn, could impede the development of the green bond market. We anticipate a negative relationship between higher fossil fuel subsidies and green bond issuance.

The fourth control variable is the total trade value of low-carbon technology products (LCARTECH), which is measured in USD and obtained from the IMF Climate Database. This factor has the potential to influence the issuance of green bonds by stimulating the demand for sustainable technologies, particularly renewable energy, and enhancing credit-risk analysis and bond pricing (Ketterer et al., 2019). High trade volume in low-carbon technology products could indicate an increasing demand for sustainable technologies and lead to a rise in the number and size of green projects. For instance, Apple Inc. (2022) financed its $4.7 billion carbon-free investment by issuing green bonds, which was made possible due to its switch to purchasing carbon-free aluminum. This trend could create more opportunities for green bond issuers and investors. Furthermore, a substantial volume of trade in low-carbon technology products may indicate a favorable policy and regulatory landscape for green finance, thereby attracting more issuers and investors to the green bond market (Tolliver et al., 2020). This could lead to a reduction in spreads (Capelle-Blancard et al., 2019). To capture these dynamics, we employ a country's comparative advantage in the low-carbon technology products index as an independent variable. We expect to observe a positive correlation between higher trade in low-carbon technology products and green bond issuance.

The fifth control variable is a country's export performance, which we measure using the export performance index (EXPPERF) sourced from the World Development Indicators. The impact of export performance on green bond issuance holds significance as it influences the economic conditions that shape the demand for green finance. A country's capacity to sell goods and services to other nations, as indicated by its export performance, can be influenced by factors like competitiveness, economic growth, and trade policies. Robust export performance can result in increased energy and resource demand, potentially leading to higher greenhouse gas emissions and generating a need for sustainable projects and initiatives (Russo et al., 2021). In such cases, green bonds may serve as a funding mechanism, allowing countries to invest in renewable energy projects to achieve their sustainability objectives. We expect to observe a negative correlation between higher export performance and green bond issuance.

The sixth control variable is a country's import performance, which is measured by the import performance index (IMPPERF), provided by the World Development Indicators. This factor also has the potential to affect the issuance of green bonds as it may influence a country's energy consumption and demand for sustainable projects (Hanieh et al., 2023). Import performance measures a country's ability to purchase goods and services from other countries, which can be affected by factors such as economic growth, competitiveness, and trade policies. If a country has strong import performance, it may lead to greater availability of goods and services, including those related to energy and sustainability. This increased availability could lead to higher energy consumption and greenhouse gas emissions, thus creating a need for investment in sustainable projects that could be financed by green bonds. We expect to observe a positive correlation between higher export performance and green bond issuance.

The seventh control variable we consider is the sovereign debt rating (RATING), which is provided by Moody's Corporation. Credit ratings serve as assessments of an issuer's creditworthiness, considering economic and non-economic information. These ratings exert a substantial influence on bond market activities, including the issuance of green bonds (Prajapati et al., 2021a, 2021b), and can significantly impact investment decisions. Additionally, ratings play a role in determining the spreads and yields of green bonds (Li et al., 2020; Sheng et al., 2021). Lower rating scores indicate higher financing costs as they reflect the issuer's ability to meet debt obligations and access capital markets (Benito et al., 2016; Wang et al., 2020). Recent literature suggests that changes in sovereign ratings can have effects on both equity and debt markets, with negative changes particularly impacting domestic and foreign markets (Rusike and Alagidede, 2021). In our study, we utilize Moody's sovereign debt ratings, categorized as investment and non-investment grade (Capelle-Blancard et al., 2019), to capture these dynamics. We anticipate that higher sovereign ratings will exert a positive influence on green bond issuance.

The eighth control variable in our study is the inflation rate (INFL), which is provided by the IMF. This variable indicates the effectiveness of macroeconomic management and its influence on the default risk of issuers. High inflation rates could lead to instability in the overall economy, reducing the creditworthiness of a state (Nickel et al., 2011). Moreover, inflation affects the availability of long-term financing (Alexopoulou et al., 2010), making it harder for governments and companies to issue bonds and increasing borrowing costs (Presbitero et al., 2016). High inflation in OECD countries has a detrimental impact on energy efficiency and could hinder the growth of the green bond market (Anh Tu et al., 2020). Recent studies have found that loose monetary policy and quantitative easing have been advantageous for bond issuance (Grosse-Rueschkamp et al., 2019; De Santis et al., 2021). In our analysis, we measure the impact of inflation by examining the percentage change in prices, and we anticipate that higher inflation rates will have a negative effect on the issuance of green bonds.

Lastly, it should be noted that both the G20 and OECD have implemented policies aimed at promoting the use of green bonds (OECD, 2020). The G20 consists of nineteen countries and the European Union, which together account for 80% of global GDP. Similarly, the OECD has recognized the significance of green finance in realizing sustainable development goals and has encouraged its members to promote green bonds as a means of financing sustainable projects. To account for this influence, we include dummy variables indicating whether a country is a member of these institutions. The appendix provides the detailed definitions of all variables.

Table 2 displays the descriptive statistics for the variables, illustrating substantial diversity among countries. The average (log) value of green bond issuance is 5.1, with a notable standard deviation of 11.3 and a maximum value of 85.6, indicating significant disparities across countries. Additionally, the mean and median values differ, indicating skewedness in the distribution of the sample. As expected, the energy diversity index varies significantly among countries, with a mean value of 0.35, a standard deviation of 0.97, and a maximum value of 5.26. Moreover, the economic and environmental variables exhibit considerable dispersion. Countries differ in their levels of commitment to environmental performance criteria, as well as their objectives regarding socially responsible investment and corporate social responsibility. Similarly, there is notable variation among countries in terms of their comparative advantages in low-carbon technology products, macroeconomic performance, and institutional conditions.

3.3. Estimation model

Unraveling a causal connection between a nation's energy policy and

Table 2
Summary statistics.

	COUNT	MEAN	SD	MIN	P25	P50	P75	MAX
GRNBND	351	5.10	11.32	0.00	0.34	1.07	4.06	85.85
ENRGDEM	337	0.52	1.23	0.00	0.05	0.14	0.36	8.47
GASEMIS	333	2.36	6.70	0.00	0.07	0.45	1.36	46.18
FOSSSUB	276	0.85	3.14	0.00	0.00	0.00	0.19	22.10
INFL	350	3.54	8.13	−10.16	−0.60	1.87	5.14	59.09
SRATING	335	3.68	0.57	1.00	3.00	4.00	4.00	4.00
LCARTECH	313	23.05	2.15	12.60	22.31	23.48	24.42	26.40
EXPPERF	328	3.31	2.65	0.22	1.78	2.60	3.49	21.08
IMPPERF	328	3.21	2.10	0.80	2.00	2.49	3.56	18.14
G20	351	0.37	0.48	0.00	0.00	0.00	1.00	1.00

Note. The table reports the summary statistics of the variables.

the initiation of green bond issuance proves intricate, primarily owing to the conceivable existence of unobserved factors that exhibit correlations with both facets—energy production paradigms and the determination to embark on green bond offerings. For example, the economic well-being of a nation affects both the choices made regarding energy policies and the willingness to channel investments into environmentally friendly endeavors using green bonds. The political climate within a country can mold both its energy policies and the priority accorded to sustainability initiatives. Governments that place a premium on ecological well-being are more inclined to endorse the issuance of green bonds. Moreover, the accessibility and uptake of clean energy technologies hold the potential to sway energy policy directions and the feasibility of green undertakings, subsequently influencing the demand for green bonds. Public awareness and sentiment concerning environmental matters have the capacity to exert influence on both the decisions related to energy policies and the desire for investments aligned with sustainability, encompassing green bonds. The comprehensive regulatory framework, spanning regulations pertaining to energy generation and financial markets alike, can cast an impact on determinations concerning both energy policies and the issuance of green bonds.

To address this challenge, we employ alternative model specifications. Initially, we utilize a pooled ordinary least squares (OLS) estimation model that incorporates country and year fixed effects to account for time-invariant and time-varying heterogeneity, respectively (Greene, 2012). However, it is important to note that OLS linear estimation has certain limitations. It cannot effectively manage nonlinear relationships, has poor extrapolation properties, is sensitive to outliers, and may suffer from attenuation bias, leading to underestimated values for the outcome variable. Despite these limitations, in our setting, OLS estimation provides a solid starting point for building models and understanding relationships in the data, and it is preferred over nonlinear estimation, as the latter may be prone to incidental parameter bias (Angrist and Pischke, 2009). The inclusion of fixed effects in the analysis helps mitigate the bias associated with OLS estimation. However, to ensure the robustness of our findings, we conduct additional sensitivity and endogeneity analyses. We only utilize non-missing observations for the variables and employ robust standard errors, adjusting for heteroskedasticity using the Huber-White sandwich estimator. The estimation model equation we utilize is as follows:

$$\boldsymbol{GRNBND_{jt}} = \boldsymbol{a} + \boldsymbol{ENRGPOL_{jt}}\,\boldsymbol{\beta_1} + \boldsymbol{X1_{jt}}\,\boldsymbol{\beta_2} + \mu_{jt} \tag{1}$$

The variables in eq. (1) are as follows: $GRNBND_{jt}$ represents the value of green bonds issued in country j in year t; $ENRGPOL_{jt}$ represents the energy production policy of country j in year t; and $X1_{jt}$ is a vector of energy, environmental, and economic controls for country j in year t. The composite error term μ_{jt} is comprised of three components: γ_j accounts for country effects, δ_t accounts for year effects, and ε_{jt} represents the error parameter, assumed to be normally distributed and to vary across countries and years. Due to the challenges associated with determining causal effects based on observed correlations, we approach our findings as indicators of association rather than causation. For simplicity, we use the term "predict" to describe relationships. Table 3 presents the pairwise correlations among the variables utilized in our main regression analysis. The table reveals that the value of green bond issuance is correlated with the energy policy variables, which provides initial evidence of a potential causal relationship. Furthermore, the table demonstrates minimal correlations among the other predictors, indicating a low likelihood of collinearity.

4. Baseline results

We utilized regression analysis to evaluate how energy policy diversity impacts the issuance of green bonds, while controlling for environmental and economic factors. The findings in Table 4 illustrate that in all the models, the coefficient of ENRGPOL is positive and statistically significant, which indicates that higher energy policy diversity is linked with higher green bond issuance values across nations. The results suggest that governments' efforts to diversify energy production structures can foster the development of renewable energy markets and signal to private investors that there will be demand for green bonds to finance sustainable energy projects. Our study reveals a close association between energy policy and green finance, as the latter plays a vital role in supporting sustainable energy technology deployment and development. Additionally, our analysis found that higher energy demand (ENRGDEM) is associated with increased green bond market issuance, indicating that greater energy demand stimulates renewable energy project investment and energy efficiency initiatives that encourage green finance. Conversely, higher greenhouse gas emissions (GASRMIS) are linked to reduced green bond issuance, implying that certain sectors and industries in the economy, such as oil and gas, or countries with elevated levels of pollution or revenue from fossil fuels, face competitive adjustment challenges in adapting to green financing markets due to their fossil-based energy production and consumption policies. Furthermore, our results also show that higher fossil fuel subsidies (FOSSSUB) are associated with lower issuance value of green bonds, indicating that such subsidies can distort the market by providing financial support to non-renewable energy sources and making it difficult for renewable energy projects to compete. The study also suggests that higher trade values of low-carbon technology products (LCARTECH) weakly impact green bond issuance, depending on various external influences. Such trade may only stimulate demand for sustainable technologies under certain conditions, thereby attracting green finance. Such conditions would depend on local incentives and other regulations that would variously encourage use of low-carbon technology products. Lower inflation rates (INFL) and better sovereign ratings (SRATING) are associated with higher green bond issuance, as lower inflation rates reduce investment uncertainty, while higher ratings indicate better issuer creditworthiness and lower spreads. Lastly, import (IMPPERF) and export (EXPPERF) performance also influence green finance decisions, depending on the type and structure of imports and exports of fossil fuel products and their implications for countries' transition to a low-carbon economy and investor attitudes towards

Table 3
Correlation matrix.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
GRNBND (1)	1									
ENRGPOL (2)	0.09	1								
ENRGDEM (3)	0.41***	−0.14***	1							
GASEMIS (4)	−0.37***	−0.12**	0.48***	1						
FOSSSUB (5)	−0.15**	−0.04	0.03	−0.01	1					
INFL (6)	0.01	−0.07	−0.07	−0.08	0.04	1				
SRATING (7)	0.17***	−0.02	0.11**	0.10*	−0.06	−0.44***	1			
LCARTECH (8)	0.33***	−0.43***	0.43***	0.39***	0.18***	−0.08	0.19***	1		
EXPPERF (9)	0.02	−0.15***	0.27***	0.33***	−0.12**	0.09	−0.20***	−0.01	1	
IMPPERF (10)	0.02	−0.20***	0.31***	0.37***	−0.14**	0.08	−0.22***	−0.04	0.47***	1
N	351									

Notes. The table reports the pairwise correlations between all the variables. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4
Baseline effects.

	(1)	(2)	(3)	(4)
ENRGPOL	3.733*	3.211**	8.552*	53.147**
	(2.217)	(1.581)	(24.367)	(24.677)
ENRGDEM	9.896**	8.023*	102.403***	64.720***
	(4.673)	(4.300)	(26.320)	(12.311)
GASEMIS	−1.198	−0.796	−19.763***	−12.159***
	(0.812)	(0.747)	(6.314)	(3.000)
FOSSSUB	0.346	0.482	−1.697***	−1.266***
	(0.434)	(0.429)	(0.502)	(0.355)
INFL	0.158**	−0.110	0.212**	−0.134*
	(0.067)	(0.082)	(0.102)	(0.080)
SRATING	3.812***	3.895***	2.462	8.514**
	(1.366)	(1.462)	(3.098)	(3.781)
LCARTECH	1.422***	0.908	−4.880	−13.119***
	(0.519)	(0.549)	(11.332)	(4.804)
EXPPERF	−0.102	−0.092	−3.630*	−8.883***
	(0.367)	(0.352)	(2.083)	(2.049)
IMPPERF	0.119	−0.338	5.110	6.490***
	(0.529)	(0.484)	(3.301)	(2.153)
adj. R^2	0.273	0.380	0.545	0.679
RMSE	11.011	10.171	8.710	7.319
F-test	7.254	9.916	.	.
Year effects	No	Yes	No	Yes
Country effects	No	No	Yes	Yes
Dummies	Yes	Yes	Yes	Yes
N	255	255	255	255

Notes. The table reports the baseline effects of the energy policy conditions on the value of green bonds issued. Additional control variables include macroeconomic and environmental variables. The pool sample period is 1991–2021. We use an OLS model with random and fixed effects as well as policy dummies. The parentheses report heteroskedasticity-robust standard errors. Model (1) includes random effects only. Model (2) includes year effects only. Model (3) includes country effects only. Model (4) includes country-year effects. Definition of variables is provided in the Appendix. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

sustainable investment project financing.

5. Sensitivity and endogeneity analysis

The estimation analysis encounters several potential challenges (Angrist and Pischke, 2009). One challenge is the presence of measurement error, where the explanatory variable may be measured imprecisely. This measurement error could introduce bias in the estimation if it correlates with the error term in the regression equation. This concern is particularly relevant in a cross-country context where measurement variability can be substantial. For instance, if the company miscalculates its initial carbon emissions baseline, the reported reduction in emissions attributed to the wind energy project might be overstated. Similarly, inaccuracies in monitoring and data collection of the actual energy generation from the wind turbines, as well as the corresponding emissions saved compared to a conventional energy source, could lead to misleading or incorrect claims of emissions reduction. Another challenge is the possibility of reverse causation, where the volume of green bond issuance may endogenously influence energy diversity policies, leading to a correlation between the error term and the regressors. For instance, companies with a diverse portfolio of renewable energy sources are more likely to be financially stable and have a solid track record in the renewable energy sector. This financial stability and track record make them attractive candidates for issuing green bonds. Investors are more willing to invest in companies with a proven commitment to renewable energy, which leads to a higher number of green bond issuances. In this scenario, it's not that the diversity of energy sources is causing the green bond issuance; rather, the financial strength and credibility established through a diverse energy portfolio are driving both the green bond issuances and the energy diversity. However, we argue that this concern is not significant in our study since the financing decisions of individual firms and governments are unlikely to impact a country's energy production policies. The latter policies are typically formulated and implemented well before the dependent variables are measured. Moreover, the extensive cross-section of countries further diminishes the potential for reverse causation. A third challenge is the omission of relevant variables, which could also introduce estimation bias, despite the inclusion of fixed effects that control for country-specific factors. In this case, the covariance between the energy diversity measure and the error term in the regression equation may be nonzero, as the effect of energy policy could be endogenous to financial considerations. To address these potential challenges, we conduct sensitivity and endogeneity analyses. We incorporate various country-level controls, fixed effects, and group dummies to mitigate these issues, and our baseline results remain robust. However, to further ensure the robustness of our findings, we perform additional sensitivity tests using alternative measurement and estimation methods, as well as endogeneity analysis.

5.1. Sensitivity analysis

The purpose of sensitivity analysis is to assess the robustness and reliability of the baseline statistical results by examining the impact of changes in assumptions, data or methods used on the conclusions drawn from the analysis. Table 5 provides the results.

The first sensitivity test uses a one-year lagged value of the key regressor (ENRGPOL_1) to capture lagged effects. Energy policies may affect green bond issuance with a time lag because it takes time for companies and organizations to adapt to new policies and for projects to be developed and implemented (Flannery and Hankins, 2013). For example, if a government announces a new policy that requires a certain percentage of energy to come from renewable sources, it may take several years for power companies to build new renewable energy infrastructure and for the supply of renewable energy to increase. Only then will companies be able to issue green bonds to finance these new projects. Similarly, it may take time for investors to become aware of the

Table 5
Sensitivity tests.

	(1)	(2)	(3)	(4)	(5)
ENRGPOL$_{_1}$	34.162*				
	(18.115)				
ENRGPOL		75.145***		38.757**	56.069**
		(25.789)		(15.815)	(22.680)
ENRGPOLSQ		18.569*			
		(17.960)			
TELECTR			−34.839***		
			(11.319)		
ENRGDEM	59.881**	64.241***	63.411***	64.830***	18.845
	(23.222)	(22.722)	(21.312)	(21.133)	(39.529)
GASEMIS	−11.217**	−12.035**	−10.835**	−11.933***	−11.691**
	(4.950)	(4.804)	(4.536)	(4.406)	(5.502)
FOSSSUB	−1.218***	−1.260***	−1.223***	−0.715***	−1.214***
	(0.288)	(0.291)	(0.281)	(0.232)	(0.290)
INFL	−0.142**	−0.135**	−0.120**	−0.085*	−0.124**
	(0.069)	(0.065)	(0.054)	(0.049)	(0.057)
SRATING	12.164**	8.681**	8.309**	7.406**	8.163**
	(5.677)	(3.592)	(3.241)	(3.010)	(3.318)
LCARTECH	−13.263***	−13.147***	−13.350***	−10.787***	−13.250***
	(4.968)	(4.869)	(4.305)	(3.694)	(4.616)
EXPPERF	−10.965***	−8.994***	−8.204***	−7.432***	−8.415***
	(2.866)	(1.771)	(1.642)	(1.429)	(1.624)
IMPPERF	8.497***	6.498***	6.934***	5.540***	6.447***
	(2.909)	(1.899)	(1.909)	(1.616)	(1.729)
adj. R^2	0.692	0.684	0.702	0.747	0.650
RMSE	7.785	7.472	7.175	5.763	7.182
Fixed effects	Yes	Yes	Yes	Yes	Yes
Dummies	Yes	Yes	Yes	Yes	Yes
N	306	337	313	297	330

Notes. The table reports the baseline effects after applying alternative variable measures and sample structures. The pool sample period is 1991–2021. We use an OLS model with fixed effects and policy dummies. Heteroskedasticity-robust standard errors in parentheses. Model (1) uses a one-year lag value of the key regressor (ENRGPOL_1) to capture lagged effects. Model (2) uses an additional squared value of the key regressor (ENRGPOLSQ) to capture nonlinear effects. Model (3) uses an alternative measure based on the total volume of electricity generation (TELECTR). Model (4) uses an alternative sample that includes only the corporate green bond market. Model (5) uses an alternative sample that excludes China (largest issuer). * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

new opportunities created by the policy and for the market for green bonds to develop. As a result, the full impact of energy policies on green bond issuance may not be immediate and may only become apparent after a time lag. Table 5, Column (1), displays the findings of the analysis. The updated estimates reveal that the energy policy diversity with a one-year lag has a positive and statistically significant impact. This new information sheds light on the time-dependent nature of the energy policy effect. However, it does not alter the qualitative findings of the baseline results in terms of their significance and direction.

The second sensitivity test adds the squared value of the key regressor ($ENRGPOL^2$) to capture nonlinear effects. Energy policies may affect green bond issuance in a nonlinear fashion for several reasons (Rehman et al., 2022). Firstly, the impact of energy policies on green bond issuance may depend on the type and scope of policies implemented. For instance, the impact of renewable energy policies may be nonlinear since the availability of renewable energy sources and their costs may vary across different regions and time periods. Secondly, the effect of energy policies on green bond issuance may also depend on the maturity and development of the green bond market. Initially, the market may be dominated by large and well-established issuers, which may be less sensitive to energy policies. However, as the market matures and becomes more diverse, the impact of energy policies may become significant, especially if policies create favorable conditions for smaller issuers. Thirdly, energy policies may exert nonlinear effects if they are introduced in response to specific events, such as natural disasters or public health crises. In such cases, the timing and scope of the policies may depend on the severity and nature of the event, and their impact on green bond issuance may be nonlinear as well. Finally, nonlinearity may also arise from the interaction of multiple factors, such as the regulatory environment, technological innovations, and investor preferences. For instance, the impact of energy policies may be more prominent when there are favorable regulations in place or when there is a high investor demand. The findings in Column (2) of Table 5 illustrate these effects. The new estimates demonstrate that both the linear and the quadratic effects are positive and significant. This suggests that the relationship between energy policies and green bond issuance involves non-linear dynamics. These additional insights provide new information regarding the effects of energy policies and highlight their time-dependent nature. However, they do not qualitatively alter the baseline results in terms of their significance and direction.

In the third sensitivity test, we use an alternative measure of energy policy, which is based on the total volume of electricity generation (TELECTR). The data for this variable is provided by the World Development Indicators. It is possible that the total size of energy production may impact a country's alignment with environmental and climate objectives, thereby influencing green bond issuance. Column (3) of Table 5 displays the new estimates, which indicate that total electricity generation has an adverse effect on green bond issuance. This might be explained by the fact that a larger energy production is associated with higher carbon emissions and other negative environmental outcomes. Green bonds are typically issued to finance projects that promote environmental sustainability, such as renewable energy and energy-efficient constructions. If a country's energy production is based on fossil fuels or other environmentally damaging sources, it may be considered less committed to combating climate change and promoting sustainability. Consequently, investor interest in green bonds issued by that country could decline (Sorrell, 2015). The new findings corroborate the baseline results, indicating that energy policy diversity away from fossil fuels is significantly associated with the value of green bond issuance.

The fourth sensitivity test changes the sample structure and considers the energy policy effect on only corporate green bond issuance. Energy policies may affect corporate and sovereign green bond issuance differently due to differences in their organizational structures, objectives, and funding sources (OECD, 2020; Moritz et al., 2021). Corporate green bonds are issued to finance environmentally sustainable projects. These companies may have different priorities and objectives than governments. Their decisions may be influenced by a variety of factors, such as market demand, reputation, and corporate social responsibility. Energy policies affect corporate green bond issuance if they create incentives (i.e., subsidies) or regulations that encourage or require companies to invest in green projects or reduce their environmental impact. On the other hand, sovereign green bonds are issued by national or subnational governments to finance environmentally sustainable projects. These bonds are typically backed by government credit and are considered low-risk investments. Energy policies may affect sovereign green bond issuance if they prioritize or allocate funding to green projects (i.e., due to political commitment), or if they create regulations or standards for environmental sustainability that influence the selection of projects financed by green bonds. The findings are presented in Column (4) of Table 5. The updated estimates indicate that energy policy diversity remains positive and significant, with a more pronounced effect. It appears that energy policies create stronger incentives (i.e., subsidies, regulations) to private companies to seek green finance relative to sovereign entities. Therefore, these new estimates do not fundamentally change the baseline results.

To further examine the potential influence of large-size bias, we conduct an additional sensitivity test by excluding China, which is the largest issuer, from the sample. This exclusion allows us to investigate if the presence of an outlier or influential point affects the results. The results from Column (5) of Table 5 showcase the findings of this analysis. The new estimates reveal that energy policy diversity exerts a positive and significant effect, with an even stronger magnitude. It appears that the effect is general across countries and does not crucially depend on the size of the issuing country. Like before, the new estimates do not alter the direction and significance of baseline effects.

Overall, the five sensitivity tests broadly confirm the direction and significance of the baseline effects of energy policy diversity on green bond issuance. While they exhibit delays and nonlinearities and are more pronounced in corporate issuances, these effects confirm the robust association between energy policy and green finance.

5.2. Instrumental variable estimation

To mitigate potential endogeneity concerns, we employ instrumental variable (IV) methods to assess the robustness of our estimates, following the approach outlined by Greene (2012). We utilize the political commitment to sustainability (SUSTCOM) index, provided by the World Economic Forum report (www.weforum.org), as an external IV instrument for our energy policy diversity variable. SUSTCOM measures the extent to which a country's political system is committed to sustainability promotion. While the instrument exhibits a strong association with the potentially mismeasured regressor, its potential measurement error is uncorrelated with the measurement error in the key institutional regressor. A country's commitment to sustainability can play a crucial role in promoting energy production diversity. A strong commitment to sustainability can result in the development and implementation of supportive energy diversity policies and regulatory frameworks (Neves and Leal, 2010). These policies can include incentives, targets, and regulations that encourage a diverse energy mix. Further, a sustainability commitment can drive investments in renewable energy technologies such as solar, wind, hydro, and geothermal power (IEA, 2022b). By providing financial support and favorable market conditions, governments can encourage the growth and deployment of renewable energy projects. This diversifies the energy mix by reducing reliance on fossil fuels and promotes the use of clean, sustainable sources of energy. As a result, a country's political commitment to sustainability acts as an instrumental variable, capturing the factors that may shape energy policy decisions in a country. To generate unbiased estimates, we apply various estimation techniques, including the two-stage least squares (2SLS) estimator, the two-step generalized method of moments (GMM) estimator, and the conditional mixed process (CMP) estimator. These methods allow us to account for endogeneity concerns and produce reliable estimates of the relationship between energy policy diversity and green bond issuance. The 2SLS and GMM estimators are employed to tackle endogeneity concerns within regression analysis. However, they exhibit distinct attributes and applications. Specifically, the 2SLS method is a specialized utilization of the broader GMM framework, intended to counteract endogeneity using instrumental variables. In contrast, GMM constitutes a more expansive approach that extends its utility to encompass a wider spectrum of issues that transcend the scope of endogeneity. The CMP estimator provides a resolution to both endogeneity and unobserved heterogeneity in a concurrent manner, leveraging maximum likelihood calculations. This estimator is particularly well-suited for scenarios where temporal-constant latent factors (individual-specific effects) and endogeneity concurrently exert influence on the model. Within the CMP estimator, facets of fixed effects and instrumental variable estimation are amalgamated, culminating in parameter estimates that are consistent and

Table 6
Endogeneity analysis.

	(1)	(2)	(3)	(4)
ENRGPOL	38.578**	38.578**	53.118**	53.147**
	(17.901)	(17.901)	(22.142)	(22.533)
ENRGDEM	9.299***	9.299***	64.720***	64.720***
	(3.599)	(3.599)	(10.072)	(22.647)
GASEMIS	−1.559**	−1.559**	−12.159***	−12.159**
	(0.768)	(0.768)	(2.165)	(4.784)
FOSSSUB	0.527*	0.527*	−1.266***	−1.266***
	(0.286)	(0.286)	(0.258)	(0.291)
INFL	0.108	0.108	−0.134*	−0.134**
	(0.150)	(0.150)	(0.073)	(0.065)
SRATING	4.765***	4.765***	8.514**	8.514**
	(1.605)	(1.605)	(3.742)	(3.571)
LCARTECH	4.251***	4.251***	−13.119***	−13.119***
	(1.390)	(1.390)	(2.024)	(4.860)
EXPPERF	0.203	0.203	−8.883***	−8.883***
	(0.560)	(0.560)	(1.671)	(1.768)
IMPPERF	1.744*	1.744*	6.490***	6.490***
	(0.945)	(0.945)	(1.992)	(1.893)
First-stage results				
SUSTCOM	−0.011***			
	(0.017)			
Second-stage statistics				
Kleibergen-Paap_LM (pv)	5.491	5.491		
	(0.019)	(0.019)		
Kleibergen-Paap_F	5.536	5.536		
Stock-Wright (pv)	25.186	25.186		
	(0.001)	(0.001)		
AR (2)		0.278		
Wald Chi^2			128.715	
Atanrho (pv)			−0.169	
			(−0.081)	
Delta (δ)				−0.163
R_{max}				1.001
Beta (β)				−6.577**
Fixed effects	Yes	Yes	Yes	Yes
Dummies	Yes	Yes	Yes	Yes
N	231	231	305	237

Notes. The table reports the results of the endogeneity analysis. The outcome variable is the value of green bonds issued. The key independent variables are the energy policy variables. Additional control variables include the macroeconomic and environmental factors. The pool sample period is 2001–2021. Model (1) uses an IV model with the 2SLS estimator. Model (2) uses an IV model with the two-step GMM estimator. Model (3) uses an IV model with the CMP estimator. The external instrument used is the political commitment to sustainability (SUSTCOM). Finally, model (4) reports the results of Oster's (2019) test of coefficient stability. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

efficient.

Table 6 displays the estimation results obtained from different IV regression models used to examine the relationship between energy policy diversity and green bond issuance. In Column (1), we present the results obtained from the 2SLS estimator. This estimator first regresses energy policy diversity on the index of commitment to sustainability, addressing the validity of the instrumental variable. The large Kleibergen-Paap F statistic indicates the validity of the IV instrument and the consistency of the 2SLS estimator. Moreover, the non-small Kleibergen-Paap LM statistic suggests that the IV variable is not weak. The elevated Stock-Wright statistic signifies a correlation between the instrument and the potentially endogenous variable, thereby gauging the degree to which the selected instrument holds relevance. This assessment is carried out by contrasting the first-stage F-statistic with critical values that consider both instrument potency and sample size. The results of the 2SLS estimator indicate that ENRGPOL remains positive and statistically significant. In Column (2), we present the results obtained from the two-step GMM estimator, which employs the lagged first differences of the dependent variable as instrumental variables (Arellano and Bover, 1995). The first and second stage results align with the findings of the 2SLS estimator, with no significant evidence of second-order autocorrelation detected. ENRGPOL also continues to exhibit a positive and significant relationship. Column (3) showcases the results obtained from the conditional mixed process (CMP) method, which estimates separate equations as a system to address potential issues related to unobserved influences (Roodman, 2011). The high LR chi^2 statistic indicates good model specification, while the insignificant Atanhrho12 correlation parameter suggests a minimal likelihood of endogeneity at the 10% level. The results obtained from the CMP estimator also demonstrate a positive and significant association between ENRGPOL and green bond issuance. Overall, the results obtained from the various estimation techniques consistently indicate that ENRGPOL remains positive and significant, reinforcing the relationship between energy policy diversity and green bond issuance.

5.3. The Oster test of coefficient stability

To ensure the robustness of our findings against omitted variable bias, we conduct further tests. While we include observed predictors in our model to mitigate potential confounding, their selection alone may not fully control for bias resulting from unobserved factors. To address this concern, we employ Oster's (2019) bias-adjusted treatment test, which examines the effect of incorporating unobserved predictors on omitted variable bias. Oster's test evaluates bias by analyzing variations in the stability of coefficients and the totally explained variation of regressors when transitioning from observed to unobserved predictors. The Oster test of coefficient stability introduces a novel approach to endogeneity analysis by focusing on the stability of the estimated coefficients across different subsamples of the data. Unlike traditional tests that examine the validity of instruments or the overall fit of the model, the Oster test specifically addresses the potential endogeneity of each single predictor variable by assessing whether its coefficient remains consistent across varying subsamples. The key novelty of the Oster test lies in its ability to detect endogeneity by leveraging changes in the estimated coefficients as the composition of the sample changes. Building upon previous work by Altonji et al. (2005), Oster (2019) developed a new method to assess bias arising from unobserved factors. The method assumes that observed predictors represent a random subset of all relevant predictors. The degree of confounding in the causal effect estimation depends on bounding the treatment effect, while setting assumptions about the selection of unobserved predictors. In the presence of omitted variables, it becomes challenging to identify the coefficient β representing the direct treatment effect on the outcome variable. Instead, a range (upper and lower bounds) of the treatment effect can be identified based on the proportionality degree, δ, between observed and unobserved predictors, as well as on the unknown overall model fit, R_{max}, which encompasses both observed and unobserved predictors. The δ parameter comes into play when interpreting the results. It represents the threshold below which changes in the coefficients are considered insignificant, and above which they are considered significant. The coefficient δ indicates the strength of correlation between unobserved predictors and the outcome variable relative to observed predictors, with larger values suggesting stronger endogeneity. When $\delta = 1$, observed and unobserved predictors have equal importance, while values of $\delta > 1$ indicate that unobserved predictors have a stronger impact, and vice versa. In general, if δ is too high, even small changes might be considered significant, leading to potential false alarms. On the other hand, if δ is too low, important changes might be missed. The choice of δ requires careful consideration and often involves a balance between sensitivity and specificity in detecting coefficient stability changes. R_{max} represents the extent of variation in the outcome variable that can be explained by controlling for both observed and unobserved predictors, but it cannot be directly estimated. Therefore, assumptions (bounds) about δ and R_{max} are necessary to identify β. In line with Oster's (2019) suggestion, we set $R_{max} = 1.3R^2$ and employ the Stata module *pascal* to generate estimates. Column (4) in Table 6 presents the results of the Oster test. The δ parameter is small and negative (-0.163), indicating that the inclusion of excluded instruments in the regression model leads to a minor change in the potentially endogenous variable ENRGPOL, suggesting a low likelihood of endogeneity. The statistically significant β coefficient ($-6.577^{**)}$ suggests that the instrumental variable is a good predictor of the endogenous variable, thereby providing valid means to address endogeneity concerns.

6. Additional robustness checks

6.1. New control variables

The relationship between energy policy diversity and green bond issuance is not straightforward, as environmental, social, economic, and geopolitical factors can all have a mitigating effect on this association. Take weather conditions, for instance, which can impact energy policy in multiple ways and consequently affect green bond issuance indirectly (Jeong, 2020). Severe weather events such as floods, hurricanes, and heat waves can disrupt energy infrastructure and supply chains, leading to temporary shortages and price increases in energy markets. This can potentially reduce investor confidence in financing green energy projects, which may decrease the demand for green bonds. Conversely, adverse weather conditions can also raise public awareness of climate change and the need for sustainable energy sources, creating political pressure for policymakers to adopt more ambitious energy policies, thereby increasing demand for green bonds. Furthermore, social conditions can influence the link between energy policy and green bond issuance (Lutzenhiser, 1993). Social norms and familial attitudes towards sustainability and environmentalism can impact the demand for green bonds and investors' willingness to invest in them. Countries with a strong emphasis on transparency, social responsibility and family connections may be more inclined to prioritize investments in renewable energy and green technologies, leading to an increase in the issuance of green bonds (Mertzanis et al., 2020; Mertzanis, 2021). In addition, geopolitical risks could also mitigate the effect of energy policy on green bond issuance (Su et al., 2021). Investors in countries experiencing political instability, or facing trade disputes, may be less willing to invest in green bonds due to economic uncertainty, even if the country has a robust energy policy.

We evaluate some of these conjectures by adding new controls separately to contain potential collinearity bias and the potential risk of confounding variables. We re-estimate Eq. (1) to include the following distinct impacts: First, to account for the effect of additional environmental effects, we include the impact of the countries' temperature (TEMP) and rainfall (RAIN) conditions. The World Development Indicators provide the data for these new controls. Second, to account for the effect of additional social effects, we include the impact of the countries' degree of social tolerance (TLRNCE) and the strength of family ties (FMLTIES). Berggren and Nilsson (2013) provide the data for tolerance, and Alesina and Giuliano (2010) provide the data for family ties. Third, to account for the effect of additional cultural and geopolitical effects, the impact of the countries' degree of power distance (PDI) and geopolitical risk (GPR). Hofstede (2001) provides the data for power distance, and Caldara and Iacoviello (2022) provide the data for geopolitical risk. The results are presented in Table 7. The inclusion of new environmental, social, and cultural variables does not fundamentally alter the positive and significant relationship between energy policy diversity and green bond issuance. Additionally, most of the added controls demonstrate statistical significance. Higher average yearly temperatures in a country are associated with a greater volume of green bond issuance, aligning with the findings of Weber and Saravade (2019). Indeed, the issuance of green bonds can be significantly influenced by prevailing weather conditions, particularly in industries that find themselves acutely vulnerable to the effects of weather-related factors and the broader impacts of climate change. The correlation between weather patterns and green bond issuance is particularly pronounced in sectors such as renewable energy, agriculture, and infrastructure, where the operational viability and long-term sustainability of projects are intricately tied to climatic variations. Moreover, stronger family ties are inversely correlated with green bond issuance. Family ties may influence green bond issuance indirectly by affecting societies' norms and values towards green finance, intergenerational concerns, collective decision-making processes, and community engagement. Lastly, geopolitical risk moderates the effect of energy policy diversity on green bond issuance. Geopolitical risk refers to uncertainties and potential disruptions caused by political events, conflicts, and tensions between countries or regions. These risks can have implications for various aspects of the economy and financial markets, including the issuance of green bonds. Overall, the additional controls moderate the impact of energy policy diversity on green bond issuance without altering the fundamental relationship between them.

Table 7
Additional robustness checks.

	(1)	(2)	(3)
ENRGPOL	41.524**	42.287*	53.142**
	(19.777)	(22.963)	(24.761)
ENRGDEM	45.061***	41.803***	64.723***
	(14.959)	(13.803)	(12.386)
GASEMIS	−8.150**	−7.667**	−12.159***
	(3.583)	(3.503)	(3.010)
FOSSSUB	−0.615	−0.626	−1.266***
	(0.863)	(0.816)	(0.359)
INFL	−0.003	0.001	−0.134
	(0.061)	(0.068)	(0.082)
SRATING	1.569	0.504	8.519**
	(2.795)	(3.284)	(3.795)
LCARTECH	5.870	7.597	−13.134**
	(7.477)	(7.855)	(5.061)
EXPPERF	−6.519*	−8.867*	−8.878***
	(3.703)	(4.936)	(2.060)
IMPPERF	2.128	4.718	6.483***
	(2.158)	(2.838)	(2.139)
TEMP	−76.930*		
	(39.940)		
RAIN	−3.423		
	(2.522)		
TLRNCE		0.056	
		(0.153)	
FMLTIES		−16.477*	
		(9.458)	
PDI			461.696*
			(265.264)
GPR			−0.012
			(0.257)
adj. R^2	0.612	0.632	0.677
RMSE	5.865	5.953	7.339
Fixed effects	Yes	Yes	Yes
Dummies	Yes	Yes	Yes
N	288	277	237

Notes. The table reports the effects of the energy policy conditions on the value of green bonds issued after adding new controls capturing macroeconomic and environmental variables. The pool sample period is 1991–2021. We use an OLS model with fixed effects and policy dummies. The parentheses include heteroskedasticity-robust standard errors. Model (1) controls for the effect of additional environmental conditions (TEMP, RAIN). Model (2) controls for the effect of additional social conditions (TLRNCE, FMLTIES). Model (3) controls for the effect of additional cultural and geopolitical conditions (PDI, GPR). * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

6.2. Dominance analysis

To identify the specific energy sources that have a greater impact on predicting the outcome variable of green bond issuance, we utilize dominance analysis (Azen and Budescu, 2006). Dominance analysis goes beyond looking solely at individual coefficients and considers the impact of predictor variables within the context of the entire model. It helps researchers understand how different predictors interact and contribute to the overall predictive power of the model. This approach allows us to determine the relative importance of individual energy sources within our statistical model. Dominance analysis draws upon the Shapley value decomposition from game theory to assess the contributions of each regressor towards prediction by comparing the overall fit statistic. In order to evaluate the relative predictive power of the individual energy sources, we employ the Stata module *domin* (Luchman, 2021) and conduct dominance analysis. This method calculates the average net increase in the overall R^2 of the model when each independent variable is added to models constructed using all possible combinations of the remaining predictors, thereby providing insights into the relative importance of each regressor. Dominance analysis can help to identify the most important predictors and provide a more accurate understanding of the relationships between the predictors and the outcome variable. Table 8 presents the outcomes of examining the green finance

Table 8
Dominance analysis.

	(1)	(2)	(3)	(4)
BIOFUEL	0.0058	0.0052	0.0060	0.0052
COAL	0.0033	0.0080	0.0048	0.0077
WIND	0.0218	0.0147	0.0214	0.0142
GAS	0.0040	0.0055	0.0043	0.0053
HYDROP	0.0101	0.0105	0.0087	0.0083
SOLAR	0.0422	0.0275	0.0436	0.0286
NUCLEAR	0.0444	0.0468	0.0369	0.0375
OIL	0.0050	0.0032	0.0045	0.0033
ENRGDEM		0.0800		0.1155
GASEMIS		0.0677		0.0984
FOSSSUB		0.0059		0.0052
INFL		0.0047		0.0058
SRATING		0.0306		0.0344
LCARTECH		0.0443		0.0501
EXPPERF		0.0033		0.0042
IMPPERF		0.0043		0.0059
Fit-stat	0.1366	0.3840	0.1302	0.4523
N	324	255	324	255

Notes. Notes. The outcome variable is the value of green bonds issued. The independent variables are the individual sources of energy production. Model (1) shows the dominant effect of each of the energy production sources on the total green bond issuance value without the control variables. Model (2) shows the dominant effect of each of the energy production sources on the total green bond issuance value with the control variables. Model (3) shows the dominant effect of each of the energy production sources on the corporate green bond issuance value without the control variables. Model (4) shows the dominant effect of each of the energy production sources on the corporate green bond issuance value with the control variables. * p < 0.1, ** p < 0.05, *** p < 0.01.

effect of each of the eight energy production sources separately: biofuels (BIOFUEL), coal (COAL), wind (WIND), gas (GAS), hydropower (HYDROP), solar (SOLAR), nuclear power (NUCLEAR), and oil (OIL). The first column indicates the principal impact of each energy source on the total value of green bond issuance without the control variables, while the second column indicates the impact with the control variables. Similarly, the third and fourth columns represent the impact of each energy source on corporate green bond issuance value without and with the control variables, respectively.

Significantly, within our dominance analysis encompassing both the comprehensive models concerning total green bond issuance and corporate green bond issuance, a standout finding emerges. It becomes evident that nuclear power (NUCLEAR) (with respective dominance values of 0.0444 and 0.0375) assumes a pivotal role as the primary predictor, wielding a notably elevated relative importance in bolstering the overall efficacy of the model. Following closely, solar energy (SOLAR) (carrying dominance values of 0.0422 and 0.0286) emerges as the second most influential predictor. Particularly noteworthy is its pronounced significance in the context of forecasting corporate green bond issuance, thereby underscoring its substantial impact within this specific domain. These are novel and interesting findings, indicating that energy policies may be more effective in promoting green finance if they diversify towards nuclear and solar energy. Nuclear energy generation may encourage green bond issuance, despite the ongoing debates and considerations surrounding its environmental impact and safety concerns (IAEA, 2022). Nuclear power is often considered a low-carbon energy source because it does not produce greenhouse gas emissions during operation. This aligns with the goal of reducing carbon emissions and combating climate change, which are central themes in the green finance and green bond market. Further, green bonds often fund projects with long-term sustainability objectives. Nuclear power plants have long operational lifetimes, and investments in nuclear energy can be aligned with long-term environmental and energy goals. Thus, the regulation and expansion of nuclear power should be reviewed with respect to its effect on green finance (Gable, 2023).

6.3. Nuclear energy, water infrastructure quality and green finance

In the previous section, the analysis showed the prominence of nuclear energy production in predicting the issuance value of green bonds. This section investigates the influence of crucial factors that may mitigate the dominant effect of nuclear energy production on green finance. One of these key factors is the quality of water infrastructure (WTINFR), which mitigates the nuclear energy production effect on green bond issuance. Nuclear energy production requires significant amounts of water for cooling and other operational processes. The availability and management of water resources directly influence the efficiency and reliability of nuclear power plants. In regions where water scarcity or water stress is a concern, the dependence on abundant water sources for nuclear energy can raise environmental and regulatory challenges (Pate et al., 2007). Green finance decisions take into account the environmental sustainability of projects, and the impact of water usage on nuclear energy operations can affect the perception of such projects' "greenness." Further, water infrastructure becomes essential for mitigating the potential environmental risks associated with nuclear energy (Usman et al., 2022). Adequate water supply is necessary for maintaining safe operating temperatures and preventing overheating of reactors. Proper water management also plays a role in preventing pollution of aquatic ecosystems. Green finance decisions may consider the level of risk mitigation measures implemented by nuclear energy projects to assess their alignment with environmental sustainability goals. The relevant data is provided in the World Economic Forum report. The quality of water infrastructure is essential for nuclear energy production because cooling nuclear power plants requires a large amount of water (Green, 2019). The cooling water eliminates the excess heat generated by the nuclear reaction, and it is critical to ensure the safe and efficient operation of the plant. When the water infrastructure is inadequate, it can cause issues such as corrosion or fouling of the cooling system, which can decrease the efficiency of the nuclear plant and increase the likelihood of equipment failure (WNA, 2021). Poor water quality can also result in environmental problems if contaminated water is discharged into rivers or other bodies of water.

We restimate eq. (1) using NUCLEAR and WTINFR and their interaction as key regressors, along with the other controls. Table 9 provides the results. As expected, the share of energy production produced by nuclear sources is a strong and positive predictor of green bond finance. Nuclear energy production can support the growth of green finance in several ways. First, nuclear power is considered a low-carbon energy source because it does not produce greenhouse gas emissions during operation. This means that nuclear energy can contribute to reducing carbon emissions and combating climate change, which is a major goal of green finance. Second, investing in nuclear energy production can help to diversify the energy mix, reducing dependence on fossil fuels and increasing energy security. This is important because the transition to a low-carbon economy requires a reliable and diverse energy supply. Third, nuclear energy can be used to produce hydrogen, which is a clean energy carrier that can be used in various sectors, such as transportation and industry. This can contribute to the decarbonization of these sectors and help to achieve climate targets. Finally, the development and deployment of new nuclear technologies, such as small modular reactors, can create opportunities for innovation and job creation in the clean energy sector, which is a key area of interest for green finance investors. In addition, the quality of water infrastructure has a direct and indirect impact on green finance, but the interaction effect is negative. This suggests that countries that prioritize nuclear power production may face challenges in supporting green finance projects due to concerns

Table 9
Nuclear power generation and water infrastructure effects on green bond issuance.

	(1)	(2)
NUCLEAR	6.671***	6.589***
	(2.390)	(2.408)
WTINFR	0.570**	0.497**
	(0.246)	(0.203)
NUCLEAR * WTINFR	−0.077***	−0.072***
	(0.025)	(0.025)
ENRGDEM	44.302***	42.034***
	(14.333)	(10.511)
GASEMIS	−8.299**	−7.795***
	(3.454)	(2.547)
FOSSSUB	−0.047	0.023
	(0.284)	(0.253)
INFL	0.010	0.007
	(0.052)	(0.045)
SRATING	1.623	1.846
	(1.847)	(1.448)
LCARTECH	4.743	3.720
	(7.746)	(5.955)
EXPPERF	−5.510*	−4.936
	(3.236)	(3.175)
IMPPERF	3.478*	3.298*
	(1.964)	(1.822)
adj. R^2	0.662	0.741
RMSE	5.439	4.139
Fixed effects	Yes	Yes
Dummies	Yes	Yes
N	292	237

Notes. The table reports the effect of nuclear power generation (NUCLEAR) on green bond issuance, of water infrastructure (WTINFR) and their interaction, for different types of green bonds. Column (1) presents the effect on all green bonds, whilst column (2) on corporate green bonds. The pool sample period is 1991–2021. We use an OLS model with fixed effects and policy dummies. The parentheses report heteroskedasticity-robust standard errors. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

about water infrastructure quality. These findings demonstrate that while nuclear energy production has a positive direct impact on green bond finance, it may also have unintended environmental consequences related to water infrastructure. These results underscore the intricate relationship between energy policies, supportive infrastructure, and green finance decision-making. Water-related regulations, such as those related to water discharge and thermal pollution, can impact the feasibility and costs of nuclear energy projects. Meeting these regulations often requires investments in water treatment and management technologies. Green finance decisions may assess the financial implications of ensuring compliance with water-related regulations and how these investments align with sustainability objectives.

7. Conclusions

This study examines the relationship between energy policy diversity and green finance across countries. Using a newly available IMF dataset, we investigate the influence of a composite measure of energy policy diversity on the level of green bond issuance in seventy countries from 1991 to 2021, while also accounting for the impact of various economic, environmental, and institutional factors. Energy policy diversity encompasses a country's degree of diversification in its sources of energy production and the policies that promote a transition to renewable energy. Our measure includes the range of energy sources, such as fossil fuels, nuclear power, and renewable energy. By ensuring energy security, reducing greenhouse gas emissions, and stimulating innovation and economic growth in the renewable energy sector, energy policy diversity can play a key role in promoting sustainable development.

Having a diversified energy policy is crucial for green finance as it promotes a more balanced and sustainable approach to energy production. When a country depends on a single energy source, it becomes vulnerable to price fluctuations, supply shortages, and environmental risks associated with that energy source. Conversely, diversifying energy policies helps countries to spread their risks across different energy sources, reducing the likelihood of disruptions. This is especially important for green finance because it fosters a more stable and predictable investment market for renewable energy. If a country is heavily reliant on a single energy source, it may struggle to attract investors to other areas, as there is a greater level of uncertainty surrounding those investments. By diversifying their energy policies, countries can create a more appealing investment environment for green finance, which can aid in driving the transition to a more sustainable energy system.

Our study is the first to examine how energy policy diversity directly affects green bond finance. Our findings indicate that countries with greater energy policy diversity tend to have higher green bond issuance values on average. This suggests that efforts by governments to diversify their energy production structures can encourage the development of renewable energy markets and signal to private investors that there will be demand for green bonds to finance sustainable energy projects. We also found that higher energy demand, lower greenhouse gas emissions, and lower fossil fuel subsidies are all associated with higher green bond issuance. Additionally, better sovereign ratings, lower inflation rates, and more active import-export performance encourage the development of green bond issuance.

However, our results also reveal that changes in energy policy diversity may not have an immediate or linear effect on green bond issuance. These highlights potential delays in investor awareness of new opportunities created by policy changes, as well as differences in the type and scope of policies implemented, the maturity of the green bond market, and the impact of specific events like natural disasters or public health crises. Moreover, various environmental, social, economic, and geopolitical factors can all influence the relationship between energy policy diversity and green bond issuance. Finally, we found that nuclear power and solar power are the leading predictors of green bond market growth among different energy sources. However, countries that prioritize nuclear power production may encounter difficulties in supporting green finance projects due to concerns about water infrastructure quality.

Our study stresses the broader role of energy production diversity in promoting green finance. Policy interventions at diversifying energy production could potentially encourage green finance in several ways. Relying heavily on a single energy source or technology can expose a region or a company to significant risks, such as price volatility, supply disruptions, and technological obsolescence. Energy production diversity helps mitigate these risks by ensuring that a portfolio of energy sources is in place, reducing vulnerability to fluctuations in fuel prices or unexpected failures. Further, climate change can impact different energy sources differently. By having a diverse energy mix, a region or company can better withstand the effects of climate change. For example, in the face of water scarcity or extreme weather events, having multiple energy sources that are less reliant on water or are less affected by weather can help maintain a stable energy supply. Moreover, green bonds are often issued to support the transition to renewable energy sources, such as solar, wind, and hydroelectric power. While these sources are more environmentally friendly, they can be intermittent due to weather conditions. Energy production diversity, including a mix of renewables and possibly some conventional sources with steady output, ensures a consistent power supply as the transition to renewables continues. In addition, a diverse energy mix encourages the development and deployment of various technologies. This can foster innovation in energy production, leading to the discovery of new, more efficient, and cleaner ways to generate power. Green bonds can fund research and development in these areas. Finally, having a diverse energy mix can improve stakeholder engagement by accommodating different perspectives and preferences. It can also address concerns about the environmental and social impacts associated with specific energy sources, making green bonds more attractive to a broader range of investors and stakeholders. Energy production diversity contributes to the long-term sustainability of energy systems. It reduces the dependence on fossil fuels and encourages the adoption of renewable sources, aligning with global efforts to combat climate change and promote a more sustainable energy future.

Furthermore, implementing strict water use efficiency standards for nuclear power plants can incentivize the adoption of advanced cooling technologies and practices that minimize water consumption. These standards could be part of broader environmental regulations or specific to the nuclear energy sector, encouraging plants to operate with reduced water needs. Compliance with such standards could positively influence the environmental credentials of nuclear energy projects, aligning them better with green finance criteria.

Although our research has uncovered the first evidence of a positive correlation between energy policy diversity and the growth of the green bond market, it has a few limitations that should be considered. One such limitation is that our measures of energy policy diversity need to be more diversified to account not only for the contribution of each individual energy source to the policy diversity measure but also for relevant governmental and regulatory policies. Additionally, the effect of energy diversity on green bond market growth may depend on issuer characteristics, such as business sector, firm size, and ownership structure, which are not provided by our data. Future research should address these characteristics. Furthermore, while we have accounted for endogeneity effects, the possibility of omitted variables bias cannot be ruled out. Finally, it is important to explicitly consider the roles of additional institutions and analyze their cross-country and longitudinal effects in greater detail. These institutions play a crucial role in shaping energy policies and influencing the issuance of green bonds. Examining their impact can provide valuable insights into the broader socio-economic and political factors that influence green finance. Therefore, future research should aim to explore the specific roles and dynamics of these institutions to further enhance our understanding of the relationship between energy policies, green bond issuance, and sustainable development.

Future research on the influence of energy generation on green finance should adopt a multidisciplinary approach that integrates environmental, economic, social, and technological perspectives to deepen our understanding of the complex relationship between energy production and sustainable finance. Future research could involve undertaking comprehensive assessments that encompass diverse energy generation technologies, considering not solely their carbon emissions, but also their wider ecological implications like water consumption, land utilization, ecological disturbances, and waste creation. Additionally, examining the life cycle analysis of distinct energy sources, while examining their effects both upstream and downstream, would offer insights into their holistic impacts and associated costs. Furthermore, investigating how nascent technologies influence both the environmental efficacy and financial feasibility of energy generation is paramount. Lastly, there's a crucial scope to scrutinize the roles of pertinent policy mechanisms and regulatory frameworks in molding the decisions of green finance concerning energy generation.

Declaration of Competing Interest

The author declares no conflicts of interest in writing this paper.

Appendix A. Variable definitions

Variable	Definition
GRNBND	Aggregate value (USD billion) of corporate and sovereign green bonds issued by each country per year, from the IMF Climate database.
ENRGPOL	Composite measure of energy policy diversity per country and year, which encompasses the shares of eight distinct energy sources: oil, coal, gas, biofuels, hydropower, solar, wind, biofuels, and nuclear power. The World Development Indicators provide the data. The measure is the first principal component of robust PCA analysis. (+)
ENRGDEM	The (log) volume of energy demand (terawatt-hours) per country and year, obtained from the BP Statistical Review of World Energy database. (+)
GASEMIS	The (log) volume of greenhouse gas emissions (million metric tons) released during energy production per country and year, obtained from the IMF Climate database. (−)
FOSSSUB	The (log) amount of fossil fuel subsidies for energy production (USD million) per country and year, obtained from the IMF Climate database. (−)
LCARTECH	The (log) total trade value of low-carbon technology products (LCARTECH) (USD million) per country and year, obtained from the IMF Climate database. (+)
EXPPERF	The index of a country's export performance (index value) per country and year, sourced from the World Development Indicators. (−)
IMPPERF	The index of a country's import performance (index value) per country and year, sourced from the World Development Indicators. (+)
RATING	The sovereign debt rating, categorized as investment vs. non-investment grade, per country and year, obtained from the Moody's Corporation. (+)
INFL	The inflation rate (percent) per country and year, obtained from the IMF Economic Outlook database. (−)
TELECTR	The (log) amount of electricity generation (terawatt-hours) per country and year, obtained from the World Development Indicators. (−)
SUSTCOM	The index of political commitment to sustainability (value) per country and year, obtained from World Economic Forum report (www.weforum.org), and used as an external IV instrument.
TEMP	The average temperature level (value) per country and year, obtained from the World Development Indicators. (+)
RAIN	The average rainfall level (value) per country and year, obtained from the World Development Indicators. (+)
TLRNCE	The degree of social tolerance towards gender and race (index value) per country, obtained from Berggren and Nilsson (2013). (+)
FMLTIES	The strength of family ties (index value) per country, obtained from Alesina and Giuliano (2010). (−)
PDI	The index of power distance (index value) as a cultural dimension, obtained from Hofstede (2001). (+)
GPR	The index of geopolitical risk (index value), obtained from Caldara and Iacoviello (2022). (−)
WTINFR	The index of water infrastructure quality (index value), obtained from the World Economic Forum report.

Notes. The sign in the parenthesis denotes the direction of expected effect on the outcome variable.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2023.107116.

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Corrigendum to “Energy policy diversity and green bond issuance around the world” [Energy Economics Volume 128, December 2023, 107116]

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The corrigendum was prompted by a model misspecification error in the originally published Table 3, which calculated pairwise variable correlations based on the total number of observations per variable, as produced by summary statistics. The revised Table 3 presents the corrected correlations, calculated using the shared number of observations across all variables. Most of the correlations remain unchanged, with only a few minor adjustments. Updated Table 3 confirms that no significant collinearity bias exists, ensuring the consistency of the subsequent regression coefficients. Additionally, the corrigendum resulted from a misplaced transferring of results in column 3 of Table 6, which reports the outcomes of the conditional mixed process regression using a maximum likelihood estimator. Due to the incomplete tabulation process of the statistical software, the results must be manually transferred, leading to the inadvertent inclusion in column 3 of previously produced less accurately specified model results. The updated column 3 of Table 6 now reflects the corrected model specification results and associated diagnostic statistics. The revised code for reproducing these results is complemented with the updated model specification. These changes in the updated Tables 3 and 6 do not challenge the validity of the research hypotheses, which remain robust as confirmed by the other specified endogeneity models in the table’s additional columns, but they do slightly affect the coefficient values. In fact, the updated coefficient values of the key variables of column 3 are stronger than the initial ones. The updated results do not affect those of the remaining analysis.

The authors would like to apologise for any inconvenience caused.

Appendix A. Supplementary data

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Table 3
Correlation matrix.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
GRNBND (1)	1										
ENRGPOL (2)	−0.09	1									
ENRGDEM (3)	0.41***	−0.14***	1								
GASEMIS (4)	0.37***	−0.12**	0.98***	1							
FOSSSUB (5)	0.15**	−0.04	0.03	−0.01	1						
INFL (6)	0.02	−0.10*	−0.06	−0.07	0.04	1					
SRATING (7)	0.17***	−0.02	0.11**	0.10*	−0.06	−0.43***	1				
LCARTECH (8)	0.33***	−0.43***	0.43***	0.39***	0.18***	−0.07	0.19***	1			
EXPPERF (9)	0.02	−0.15***	0.27***	0.33***	−0.12**	0.06	−0.20***	−0.01	1		
IMPPERF (10)	0.02	−0.20***	0.31***	0.37***	−0.14**	0.06	−0.22***	−0.04	0.87***	1	
G20 (11)	0.26***	−0.22***	0.44***	0.40***	0.28***	0.10*	−0.09*	0.52***	−0.04	−0.02	1

Notes. The table reports the pairwise correlations between all the variables.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6
Endogeneity analysis.

	(1)	(2)	(3)	(4)
ENRGPOL	38.578**	38.578**	61.192***	53.147**
	(17.901)	(17.901)	(22.177)	(22.533)
ENRGDEM	9.299***	9.299***	63.640***	64.720***
	(3.599)	(3.599)	(19.620)	(22.647)
GASEMIS	−1.559**	−1.559**	−11.966***	−12.159**
	(0.768)	(0.768)	(4.101)	(4.784)
FOSSSUB	0.527*	0.527*	−1.258***	−1.266***
	(0.286)	(0.286)	(0.255)	(0.291)
INFL	0.108	0.108	−0.126**	−0.134**
	(0.150)	(0.150)	(0.051)	(0.065)
SRATING	4.765***	4.765***	8.751***	8.514**
	(1.605)	(1.605)	(3.050)	(3.571)
LCARTECH	4.251***	4.251***	−13.002***	−13.119***
	(1.390)	(1.390)	(4.144)	(4.860)
EXPPERF	0.203	0.203	−8.760***	−8.883***
	(0.560)	(0.560)	(1.445)	(1.768)
IMPPERF	1.744*	1.744*	6.375***	6.490***
	(0.945)	(0.945)	(1.585)	(1.893)
G20	−1.890	−1.890	86.780***	88.982***
	(1.512)	(1.512)	(19.623)	(22.983)
Kleibergen-Paap LM stat	5.491**	5.491**		
Kleibergen-Paap F stat	5.536	5.536		
Stock-Wright stat	25.186***	25.186***		
AR (2)		2.96		
Wald Chi^2			1833.945	
Atanhrho (p-v)			−0.274	
			(0.411)	
Delta				−0.174
R_{max}				1.000
Beta				−6.179
Dummies	Yes	Yes	Yes	Yes
N	200	200	275	255

Notes. The table reports the results of the endogeneity analysis. The outcome variable is the value of green bonds issued. The key independent variables are the energy policy variables. Additional control variables include the macroeconomic and environmental factors. The pool sample period is 2000–2021. Model (1) uses an IV model with the 2SLS estimator. Model (2) uses an IV model with the two-step GMM estimator. Model (3) uses an IV model with the maximum likelihood estimator. The external instrument used is the degree of political commitment to sustainability. Finally, model (4) uses Oster's (2019) test of coefficient stability. The Appendix provides the definition of variables.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.