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Environmental information disclosure and idiosyncratic volatility of China's energy sector: Firm-specific risk or information asymmetry?

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ABSTRACT

This paper investigates the impact of environmental disclosure by companies in the Chinese energy sector on idiosyncratic volatility in their expected stock returns. Using a panel dataset of A-share listed firms in the Chinese energy sector and environmental disclosure scores from 2011 to 2020, the study finds that environmental disclosure is positively and robustly correlated with idiosyncratic volatility, reflecting firm-specific return variations unexplained by conventional asset pricing models. This relationship arises from environmental disclosure increasing investor concerns and perceptions of associated risks. However, the positive relationship between environmental disclosure and idiosyncratic volatility weakens significantly when renewable energy companies disclose environmental information, while it intensifies for fossil fuel energy companies. Furthermore, the study rules out the possibility that environmental disclosure serves as a noisy measure, even within China's mixed system of mandatory and voluntary disclosure. The findings validate the differential impacts of environmental risks and pollution levels associated with various energy types on idiosyncratic volatility but challenge the managerial opportunism theory, which suggests that environmental disclosure induces information asymmetry in the energy sector. These results offer important implications for policymakers, investors, and researchers.

KEYWORDS

Energy sector; environmental disclosure; idiosyncratic volatility; information asymmetry; renewable energy

1. Introduction

It is globally acknowledged that unrestricted human production activities drive economic development but, concomitantly, cause irreversible environmental pollution (Bashir et al. 2020). For instance, the fossil energy industry, characterized by high energy consumption and high pollutant emissions (e.g., CO2, SO2), poses significant threats to both ecological systems and national energy security (Jiang, Zhou, and He 2021). As the largest energy consumer globally, China is grappling with severe environmental pollution driven by large-scale exploitation and substantial reliance on fossil energy (Chang et al. 2017). Specifically, China's heavy dependence on coal in its energy mix and the rapid increase in carbon emissions have intensified the country's contributions to climate change (L. Zhang et al. 2017). In response, the Chinese government unveiled carbon peaking and carbon neutrality targets during 2020. Consequently, it is crucial for China to devise a carbon neutrality pathway that maximizes economic output while minimizing energy consumption and carbon emission intensity (Liu et al. 2023). According to T. Zhang, Zhang, and Qu (2022), by 2030, non-fossil energy sources are projected to constitute 43% of China's primary energy consumption, and non-fossil energy is expected to become the predominant energy source by 2050. Unsurprisingly, corporate environmental

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responsibility has garnered significant attention as a critical tool to address China's urgent ecological challenges. Environmental responsibility not only compels companies to manage industrial emissions but also encourages the adoption of renewable energy sources, owing to their lower environmental impact.

Environmental information disclosure plays a pivotal role in advancing these goals. It not only reduces pollution and improves energy efficiency but also exerts significant influence on the public, including investors[1] (Benlemlih et al. 2018; Caritte, Acha, and Shah 2015; Cordeiro, Profumo, and Tutore 2020). Prior research highlights that environmental disclosure, as a key component of sustainable information disclosure, affects investors' decision-making processes, thereby influencing stock prices and corporate image. This, in turn, motivates companies to enhance their environmental practices and fulfill their social responsibilities (D. D. Lee and Faff 2009; Sullivan and Gouldson 2012). For instance, Chen, Wang, and Wang (2021) and Ng and Rezaee (2020) found that corporate responsibility disclosures are integrated into stock prices, as these disclosures positively correlate with stock price informativeness. Environmental disclosure can also impact idiosyncratic volatility, which reflects firm-specific risks that are not captured by asset pricing models. Ferreira and Laux (2007) suggest that idiosyncratic volatility serves as a proxy for private information flow about firms and the informativeness of share prices. Within the context of this study, environmental disclosure enhances the informativeness of share prices by providing critical insights into a firm's environmental practices. This increased transparency encourages more informed trading and analysis, leading to greater private information production as investors delve deeper into the disclosed information to gain a competitive edge. Consequently, the variability in stock prices becomes more reflective of firm-specific risks and opportunities, influenced by the level and quality of environmental disclosures, which, in turn, increases idiosyncratic volatility.

While some studies argue that environmental disclosures reduces idiosyncratic risk by building a favorable reputation and attracting customers and stakeholders (Cheng, Ioannou, and Serafeim 2014; L. Luo, Lan, and Tang 2012; Matsumura, Prakash, and Vera-Munoz 2014; Qiu, Shaukat, and Tharyan 2016), others suggest that environmental disclosure can be perceived negatively by investors. For example, S.-Y. Lee, Park, and Klassen (2015) argue that investors associate environmental disclosure with the potential costs of improving environmental performance, particularly in polluting industries like energy. Given the polluting nature of the energy sector, environmental disclosure may amplify concerns about environmental risks and the financial burden of compliance, potentially outweighing its benefits.

Information asymmetry is another factor contributing to idiosyncratic volatility. The challenge of providing sufficient, accurate, and transparent environmental information has sparked debates over whether environmental disclosure reduces information asymmetry between companies and investors (Cormier and Magnan 2015; Tzouvanas et al. 2020). Notably, most of these studies focus on developed countries, where environmental disclosure is typically voluntary. In contrast, China operates under a mixed system where environmental disclosure requirements vary by industry (Fonseka, Rajapakse, and Tian 2019). For example, in voluntary disclosure settings, investors may find environmental disclosure more informative about idiosyncratic risks compared to mandatory disclosures (Nelson and Pritchard 2016). However, limited research has explored the implications of China's mixed disclosure system and the unique challenges posed by the energy sector's polluting nature. This study addresses these gaps by examining the relationship between environmental information disclosure and idiosyncratic volatility in China's energy sector.

Grounded in *Legitimacy Theory*, which posits that organizations strive to align their operations and disclosures with societal norms and expectations to maintain legitimacy, this study highlights the dual role of environmental disclosures. In the energy sector, such disclosures may reveal risks that challenge investor perceptions and undermine firm

[1]Refer to Bu et al. (2022) for a detailed mechanism on the effect of environmental disclosure in reducing pollution and improving energy efficiency.

legitimacy. Building on this theoretical foundation, the study explores the impact of environmental disclosure on idiosyncratic volatility, with a focus on distinguishing between substantive and symbolic disclosures.

Using a panel dataset covering companies in China's energy sector from 2011 to 2020, the study finds a significant positive relationship between environmental disclosures and idiosyncratic volatility. This effect arises as environmental disclosure heightens investor concerns and perceptions of related risks. Moreover, by analyzing the differential effects across energy types (fossil fuel and renewable energy), the findings confirm that environmental disclosure exposes fossil fuel energy companies to heightened environmental risks, thereby amplifying idiosyncratic volatility. Conversely, renewable energy companies experience a weaker relationship, consistent with their lower environmental risk profile. Additionally, the study rules out the possibility that environmental disclosure serves as a noisy measure, even under China's mixed system of mandatory and voluntary disclosure. Finally, the robustness of the findings is confirmed through a series of additional tests, including substituting total return volatility for idiosyncratic volatility, employing alternative models to measure idiosyncratic volatility, applying the instrumental variables method, and utilizing two-stage least squares (2SLS) regression.

Our study contributes to the extant literature in three distinct ways. First, unlike prior studies that focus on the cost of financing for energy companies (Fonseka, Rajapakse, and Tian 2019), this research examines idiosyncratic volatility to provide deeper insights into the market's perception of firm-specific risks and uncertainties related to environmental disclosure. This approach allows us to investigate how the level and quality of environmental disclosure influence the perceived risks and opportunities specific to energy firms in the Chinese market. By doing so, this study offers new insights into the relationship between environmental information disclosure and idiosyncratic volatility in China's energy sector. Contrary to prior research reporting an inverse relationship between environmental disclosure and idiosyncratic volatility, our findings reveal that environmental disclosure in the energy sector raises investor concerns, which are interpreted as greater risk, thus increasing idiosyncratic volatility. These findings suggest that earlier conclusions – stating that environmental disclosure reduces idiosyncratic risk – may have overlooked the heterogeneous polluting nature of firms. Furthermore, to the best of our knowledge, this study is the first to examine how the relationship between environmental disclosure and idiosyncratic volatility varies across different types of energy sources.

Second, this study contributes to the practice of investment risk management by emphasizing the crucial role of information disclosure in securities transactions. Specifically, we find that the positive relationship between environmental disclosure and idiosyncratic volatility serves as a key factor influencing investors' decision-making toward rational investment in energy stocks. This assumes a certain level of market efficiency in China's A-share markets, as supported by the findings of Laurence, Cai, and Qian (1997) and Y. Meng et al. (2023). Finally, our results have significant implications for regulators and contribute to promoting the sustainable growth of China's energy sector. Given the strong link between the environmental disclosure of the energy sector and both ecological sustainability and the stable operation of energy companies, it is beneficial for regulatory authorities to enhance the development and oversight of environmental information disclosure mechanisms. Such efforts would encourage energy firms to adopt more responsible practices, ultimately reducing associated risks.

The remainder of the paper is structured as follows: The next section reviews the relevant literature and discusses the study's theoretical framework and hypotheses. Section 3 outlines the research methodology, including the data and sample employed. Section 4 presents the main empirical tests, including robustness checks, and discusses the study's key findings. Section 5 concludes the paper by highlighting key implications and outlining avenues for future research.

2. Literature review and hypothesis development

2.1. Theoretical framework

According to *Legitimacy Theory*, corporate disclosure is often perceived as a legitimate social contribution that strengthens ties with stakeholders, making firms less vulnerable to external and internal shocks. However, the extent to which environmental disclosure enhances transparency or exacerbates uncertainty depends on the nature of the disclosed information. Firms driven by legitimacy motives may prioritize compliance-related disclosures while reducing firm-specific environmental disclosures. By emphasizing regulatory compliance rather than providing firm-specific details, companies may limit the informativeness of their disclosures, making it more difficult for investors to assess their true environmental responsibility. This lack of transparency can heighten market uncertainty and, consequently, lead to greater idiosyncratic volatility.

In addition, companies may adopt one of two contrasting approaches to disclosure within the *Legitimacy Theory*: the *Substantive* or *Symbolic approach* (Ashforth and Gibbs 1990). The Substantive approach involves disclosures that reflect genuine, material changes in a firm's activities, with numerous studies linking business disclosures to this approach (Clarkson et al. 2008; Dhaliwal et al. 2012; Stellner, Klein, and Zwergel 2015). In contrast, the Symbolic approach refers to companies presenting behaviors that appear aligned with societal norms and expectations without making substantive changes to their actual performance or policies (Ashforth and Gibbs 1990; Cho and Patten 2007). For instance, Erragragui (2018) argued that controversial firms engage in "greenwashing" by disclosing information that emphasizes a positive perception of their sustainable activities to offset negative impressions of their controversies. As such, environmental disclosures driven by symbolic motives may not always be interpreted by investors as evidence of strong environmental performance (Al-Tuwaijri, Christensen, and Hughes Ii 2004) and, in some cases, may even exacerbate information asymmetry between corporate managers and investors.

Information asymmetry has been identified as one of the contributing factors to idiosyncratic volatility (Aabo, Pantzalis, and Park 2017; Bhagat, Marr, and Thompson 1985; Krishnaswami and Subramaniam 1999). According to *Managerial Opportunism Theory*, managers may exploit opportunities to selectively disclose information – either under- or over-disclosing it – to serve their own interests. This opportunistic behavior heightens information asymmetry between firms and shareholders, potentially increasing idiosyncratic volatility. Another determinant of idiosyncratic volatility is the informativeness of stock prices. Ferreira and Laux (2007) demonstrated that higher idiosyncratic volatility is associated with fewer anti-takeover provisions, as this environment encourages investors to trade based on private information. Similarly, Ng and Rezaee (2020) and Chen et al. (2021) observed that Environmental, Social, and Governance (ESG) factors, as firm-specific information, are incorporated into stock prices by investors. Consequently, under the Substantive approach, the effect of information disclosure on idiosyncratic volatility depends on whether the disclosed information mitigates or exacerbates the firm's specific risks.

Furthermore, the legitimacy pressures faced by fossil fuel and renewable energy firms differ significantly due to their distinct environmental risk profiles. Fossil fuel firms, which are inherently associated with high carbon emissions and environmental degradation, are subject to greater public scrutiny and regulatory pressure. Consequently, when these firms disclose environmental information, it may amplify investor concerns about their exposure to environmental liabilities, regulatory risks, and potential greenwashing. This heightened uncertainty contributes to increased idiosyncratic volatility. In contrast, renewable energy firms are generally perceived as contributors to sustainability and environmental solutions. Their environmental disclosures serve to reinforce legitimacy, reassuring investors and reducing uncertainty. As a result, environmental disclosure in renewable energy firms is more likely to stabilize investor sentiment, thereby lowering idiosyncratic volatility. This asymmetric effect underscores the moderating role of energy type in the relationship between environmental disclosure and idiosyncratic volatility.

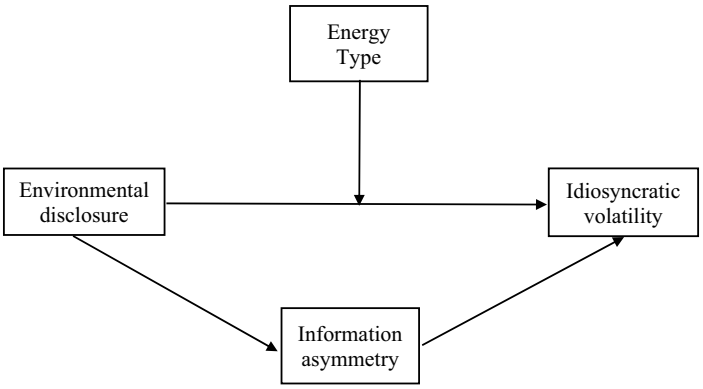

Figure 1. Research framework.

In summary, these theories propose two mechanisms linking environmental disclosure to idiosyncratic volatility: a mediation effect through information asymmetry and a moderating effect of energy type (see Figure 1). First, under the Substantive approach, the impact of environmental disclosure on idiosyncratic volatility is twofold: it may increase volatility if the disclosed information reveals potential risks, or decrease volatility if it highlights factors that mitigate firm-specific risks. Conversely, Symbolic environmental disclosures may exacerbate information asymmetry, thereby amplifying idiosyncratic volatility. Second, energy type serves as a key moderating factor in this relationship, as the effect of environmental disclosure on idiosyncratic volatility varies between fossil fuel and renewable energy firms.

2.2. Environmental disclosure and idiosyncratic volatility

From the perspective of risk mitigation, the general relationship between corporate environmental responsibility and corporate risk is often found to be negatively correlated. Several studies support this risk-reduction hypothesis. For example, Heflin and Wallace (2017) found that greater environmental disclosure reduces shareholder wealth losses caused by disasters. Similarly, Cai, Cui, and Jo (2016) argued that environmental engagement provides insurance-like effects, stabilizing stock prices following the announcement of unfavorable events. In this context, Le, Van Le, and (2019) demonstrated that environmental disclosure is significantly and negatively associated with the cost of equity capital, while Hoepner et al. (2016) found that environmental responsibility reduces the cost of debt. Collectively, these studies suggest that listed companies can benefit from environmental protection measures and information disclosure.

However, the dynamics of environmental responsibility in heavily polluting industries, such as the energy sector, differ significantly from those in less polluting industries. For energy companies, environmental responsibility is often perceived as an effort to enhance corporate reputation rather than a commitment to genuine environmental improvements (Godfrey, Merrill, and Hansen 2009). These firms are inherently associated with the perception that their profits come at the expense of public welfare and environmental sustainability. Furthermore, environmental damages caused by energy companies often necessitate investments in environmentally responsible projects, which may generate negative present value and increase overall firm risk (Déjean and Martinez 2009; Richardson and Welker 2001). Additionally, the public may view environmental disclosure by energy companies as a form of "greenwashing," intended to distract from their polluting activities rather than reflecting meaningful environmental performance (Campbell 2007; Michelon et al. 2016). Such perceptions can raise concerns

among investors about the motives behind environmental disclosures, ultimately undermining their intended purpose. More importantly, firms driven by legitimacy motives may increase compliance-related disclosures while reducing firm-specific environmental disclosures. When disclosure is primarily regulatory and lacks firm-specific details, it becomes less informative for investors, making it difficult to assess a firm's true environmental responsibility. This lack of transparency can heighten market uncertainty, leading to greater investor skepticism and, ultimately, increasing idiosyncratic volatility. In this context, environmental disclosure by firms in the energy sector may not effectively mitigate firm risk and could instead produce unintended, counterproductive consequences.

Further evidence highlights the negative investor response to environmental disclosures by polluting companies. J. Meng and Zhang (2022) found that such disclosures often elicit significant negative reactions, particularly in industries with high pollution levels. Disclosures related to air quality, climate change, ecological impacts, and waste management can exacerbate concerns about the risks faced by energy companies. For instance, Jung, Herbohn, and Clarkson (2018) demonstrated that lending institutions consider a firm's carbon-related risk exposure when making lending decisions, with such exposure significantly affecting the firm's cost of financing. Similarly, investors may factor in risks associated with environmental pollution, high compliance costs, potential replacement by cleaner technologies, and the risk of obsolescence due to future regulatory changes (Fonseka, Rajapakse, and Tian 2019; Leisen, Steffen, and Weber 2019). These risks, collectively referred to as "carbon risk" (Labatt and White 2011), contribute to investors' heightened concerns and uncertainty.

Consequently, substantive environmental disclosure may adversely impact managerial performance. For example, managers may face criticism, or companies may incur significant pollution control costs as a result of providing environmental information (S.-Y. Lee, Park, and Klassen 2015; Wagner et al. 2002). Empirically, Alareeni and Hamdan (2020) also highlight that environmental disclosure is negatively associated with company performance. also found that environmental disclosure is negatively associated with firm performance. Higher compliance costs induced by environmental regulations can weaken innovation incentives, adversely affect productivity growth and competitiveness, and further impact profitability and cash flows (Y. Wang, Sun, and Guo 2019).

Given the potential negative impacts of environmental disclosure on the energy sector, this study leverages Legitimacy Theory to formulate its first hypothesis. While environmental disclosure is often intended to enhance legitimacy, in the case of the energy sector, such disclosure may inadvertently highlight "carbon risks" and other environmental concerns. These disclosures may lead investors to adjust their expectations and trading behaviors, thereby increasing the idiosyncratic volatility of energy firms' stocks. In summary, we hypothesize that:

H1: Environmental information disclosure is positively correlated with the idiosyncratic volatility of stocks in the energy sector.

2.3. Joint effects of environmental disclosure and energy type on the idiosyncratic volatility

Fonseka, Rajapakse, and Tian (2019) found that investors assign lower costs of equity to companies with lower-polluting energy types compared to those with higher-polluting energy types, suggesting that investors factor in the pollution intensity and environmental risks associated with different energy types. The primary sources of energy can be categorized into fossil fuels and renewable energy. Fossil fuels, including coal, oil, and gas, are major contributors to environmental degradation. China's excessive reliance on coal, in particular, has led to severe pollution and ecological challenges (B. Xu and Lin 2018). In contrast, renewable energy is recognized as a critical solution to pollution and climate change (Xia and Song 2017). Renewable energy sources – such as solar, wind, water, biomass, geothermal, and ocean energy – are continuously regenerative and play an essential role in optimizing the

energy structure, protecting the environment, reducing greenhouse gas emissions, and addressing climate change. These characteristics set renewable energy apart from fossil fuels in terms of both investor perception and risk exposure. Moreover, renewable energy companies typically face fewer regulatory risks and lower compliance costs compared to fossil fuel companies, which are subject to stricter regulations and higher potential penalties (Fonseka, Rajapakse, and Tian 2019). This disparity in regulatory pressure further differentiates the environmental risk profiles of the two energy types and influences how investors respond to their environmental disclosures.

Based on *Legitimacy Theory*, we propose that renewable energy firms, which are generally perceived as more environmentally responsible, elicit a distinct investor reaction to environmental disclosures compared to fossil fuel firms. For renewable energy firms, environmental disclosures reinforce their legitimacy, reduce investor concerns, and signal a commitment to sustainable practices. As a result, these disclosures are likely to stabilize stock performance and reduce idiosyncratic volatility. In contrast, fossil fuel firms face amplified investor concerns when they disclose environmental information, as such disclosures highlight the substantial carbon-related risks and regulatory pressures associated with their operations. These heightened concerns may lead to greater uncertainty and increased idiosyncratic volatility. In light of these arguments, the following hypothesis is proposed:

H2: The relationship between environmental disclosure and idiosyncratic volatility differs based on the energy type. For fossil fuel energy firms, increased environmental disclosure amplifies idiosyncratic volatility due to heightened investor concerns over environmental risks. In contrast, for renewable energy firms, increased environmental disclosure reduces idiosyncratic volatility as it signals lower carbon risk and fosters positive investor perceptions.

2.4. Environmental disclosure and information asymmetry

In Hypothesis 1, we argue that firms employing a "substantive" approach to environmental information disclosure can influence idiosyncratic volatility. However, given China's mixed reporting system, firms may instead adopt a "symbolic" approach, which can lead to increased information asymmetry. This information asymmetry, acting as noise in the stock market, may also contribute to idiosyncratic volatility (Aabo, Pantzalis, and Park 2017). Li et al. (2019) and Feng, Chen, and Tang (2018) found that, due to the lack of standardized guidelines for environmentally responsible disclosures in China, firms in different sectors adopt varying disclosure strategies. As a result, managers in energy companies may symbolically underdisclose or selectively disclose environmental information to obscure the consequences of their businesses' actions or to emphasize overly positive environmental information to mask opportunistic behavior.

According to *Legitimacy Theory*, symbolic disclosures are superficial practices designed to manage external perceptions rather than reflect substantive environmental actions. Such disclosures can undermine a firm's legitimacy by increasing information asymmetry between the firm and its stakeholders. This heightened information asymmetry, serving as a proxy for noise in the stock market, creates uncertainty for investors and may exacerbate idiosyncratic volatility. To examine whether managers engage in "symbolic" environmental disclosure, causing the environmental disclosure score to act as noise in the stock market, we propose that information asymmetry may serve as a mediating variable in the relationship between environmental disclosure and idiosyncratic volatility.

H3: Information asymmetry has a mediating effect between environmental disclosure and idiosyncratic volatility of energy stocks.

3. Methodology

3.1. Samples and data

The Refinitiv Eikon database classifies the energy sector into fossil fuel and renewable energy companies. A spin-off from Thomson Reuters, Refinitiv Eikon is a premier financial information and analytics platform tailored for professionals in the financial services industry. Using Refinitiv's TRBC Economic Sector Codes—5010 for fossil fuel companies and 5020 for renewable energy companies – we initially compiled a list of 125 Chinese listed energy firms.

This list was then used to retrieve environmental disclosure data for the ten-year period from 2011 to 2020 from the Bloomberg Terminal. Due to Bloomberg environmental disclosure data being unavailable for certain companies, our final sample consists of 84 A-share listed companies, including 59 fossil fuel firms and 25 renewable energy firms. Information asymmetry measures were obtained from the Chinese Wind Financial Database, while data for control variables were sourced from the China Stock Market & Accounting Research (CSMAR) Database. The estimations in this study are based on an unbalanced panel dataset. To address potential outliers, all continuous variables were winsorized at the 1% and 99% levels.

3.2. Variables in the study

3.2.1. Idiosyncratic volatility

Following Rajgopal and Venkatachalam (2011), the idiosyncratic volatility is calculated based on the three-factor expected return model proposed in Fama and French (1993):

$$r_{i,d} = \alpha_i + \beta_i r_{m,d} + h_i HML + s_i SMB + \varepsilon_i \quad (1)$$

Where $r_{i,d}$ is the excess return for stock i on day d; $r_{m,d}$ is the excess return from value-weighted market index on day d; High minus Low (HML) is the difference each day between high book-to-market and low book-to-market firms. Small minus Big (SMB) is the daily difference of the return on small and large firms. The regression is repeated on a yearly basis to get the standard deviation of the residuals for each firm. As the measure of idiosyncratic volatility, we annualized the standard deviation by multiplying it the square root of the number of trading days per year for the relevant stock.

3.2.2. Environmental disclosure

This study uses the Bloomberg ESG (Environmental, Social, and Governance) disclosure score as a proxy for the quality and magnitude of environmental disclosure. Bloomberg has been providing ESG data since 2009, following its acquisition of the UK-based company New Energy Finance, which specializes in renewable energy and carbon market information.

The Bloomberg environmental disclosure score ranges from 0.1 (for firms with minimal environmental information disclosure) to 100 (for firms with full disclosure) and is weighted based on the importance of individual indicators, adjusted for each industry. The score evaluates multiple dimensions of environmental impact and sustainability efforts, including air quality, climate change, ecological and biodiversity impacts, energy consumption and efficiency, materials and waste management, supply chain practices, and water usage. For fossil fuel companies, the environmental disclosure score assesses their management of emissions, energy efficiency, and compliance with environmental regulations, emphasizing areas where they face significant environmental risks. In contrast, renewable energy companies are evaluated based on their use of sustainable resources, emissions reductions, and contributions to mitigating climate change. These components are particularly relevant to firms in the energy sector due to their significant environmental footprint. [2]

[2]The detailed components measured in the Bloomberg Environmental Disclosure Scores are presented in the appendix.

The Bloomberg Terminal is widely recognized as a reliable data source in both business analysis and academic research. Numerous environmental and financial studies have employed Bloomberg environmental disclosure data in their analyses (Eliwa, Aboud, and Saleh 2021; Hassan 2018; Ng and Rezaee 2020; Papoutsi and Sodhi 2020), further affirming its credibility and utility in this study.

3.2.3. Information asymmetry

This paper uses Amihud (2002)'s stock illiquidity measure (ILLIQ) as the measure of information asymmetry. The ILLIQ is calculated as year average value of daily absolute return divided by Chinese Yuan (CNY) trading volume of the respective day, and then multiplied by 10^7. This ratio captures the influence of the trading order flow on stock price in each day and indicates investor's capability to buy and sell a stock without influencing its prices. High ILLIQ represents greater information asymmetry. The calculation is delineated below:

$$ILLIQ_{iy} = 1/D_{iy} \sum_{t=1}^{D_{iy}} \frac{|R_{iyd}|}{VOLD_{iyd}} \tag{2}$$

where D_{iy} represents the number of trading days of stock i in year y. R_{iyd} represents the stocks daily return in year y, while $VOLD_{iyd}$ represents the corresponding daily volume in CNY.

In addition to Amihud (2002)'s illiquidity measure (ILLIQ), we also use Silber (2005)'s bid-ask spread (Bid-Ask) as another measure of information asymmetry. The bid-ask spread is computed as [(Ask-Bid)/((Ask+Bid)/2)]*100 and is the yearly mean of daily bid-ask spreads expressed in percentage.

3.2.4. Control variables

Based on previous research, variables that were significantly correlated with idiosyncratic volatility are controlled, including stock return performance (RET), firm size (SIZE), profitability (ROA), leverage (LEV), book-to-market ratio (BM), institutional ownership (INS), and firm age (AGE). RET is measured as the annual buy-and-hold return over the same period (Duffee 1995). ROA is the net income divided by total assets (Shan, Taylor, and Walter 2014). SIZE is the natural logarithm of the total assets (Z. Wang and Sarkis 2017). LEV equals long-term debt to total assets (Shan, Taylor, and Walter 2014). BM is computed as equity book value divided by to equity market value (Rajgopal and Venkatachalam 2011). INS is the percentage of stocks held by institutional investors (Y. Xu and Malkiel 2003). AGE is the log of number of years since the company was founded (Aabo, Pantzalis, and Park 2017).

3.3. Descriptive statistics and correlations

Table 1 presents the descriptive statistics of the variables of this study. The average idiosyncratic volatility (IV) is 36.55% with a standard deviation (SD) of 12. The mean environmental disclosure

Table 1. Descriptive statistics.

	N	Mean	SD	Min	Max
IV	793	36.55	12.00	12.27	69.63
ENVD	378	13.35	10.54	1.550	46.51
RET	776	0.0384	0.421	−0.606	2.578
ROA	792	0.0213	0.0504	−0.275	0.140
SIZE	793	15.93	1.108	14.13	20.67
BM	793	0.619	0.415	0.0523	2.295
LEV	675	0.0648	0.0715	0	0.360
INS	794	50.52	27.34	0.252	97.53
AGE	788	2.727	0.332	1.609	3.367
ILLIQ	793	0.0042	0.0043	0.0002	0.0399
Bid-Ask	794	16.14	6.397	6.405	45.70

Table 2. Correlation coefficients between the variables.

	IV	ENVD	RET	ROA	Size	BM	LEV	INS	AGE	ILLIQ	Bid-Ask
IV	1										
ENVD	−0.219***	1									
RET	0.356***	0.04	1								
ROA	−0.127***	0.201***	0.027	1							
SIZE	−0.237***	0.620***	0.115***	0.219***	1						
BM	−0.465***	0.372***	−0.248***	0.022	0.276***	1					
LEV	−0.170***	0.277***	−0.104***	−0.059	0.285***	0.237***	1				
INS	−0.258***	0.335***	−0.047	0.173***	0.538***	0.355***	0.254***	1			
AGE	−0.149***	0.048	0.03	−0.052	−0.04	0.158***	0.110***	0.128***	1		
ILLIQ	0.127***	−0.351***	−0.037	−0.043	−0.527***	−0.123***	−0.280***	−0.132***	0.28	1	
Bid-Ask	−0.108***	−0.258***	−0.045	−0.235***	−0.292***	0.200***	0.030	−0.076**	0.225***	0.366***	1

***, **indicate significance at the 1% and 5% levels, respectively.

score (EVND) is 13.35 with a standard deviation of 10.54. Regarding the control variables, the stock returns (RET) have a mean of 0.0384 with a standard deviation of 0.42. According to our samples, companies have an average ROA of 0.0213. The book-to-market (BM) ratio indicates that the book value is 61.9% of the market value of equity on average. The leverage (LEV) has a mean value of 6.48%. The average proportion of shares held by institutional investors is 50.52%, indicating that the sample companies have a high shareholding concentration, and the major shareholders have a significant impact on the company. The log age (AGE) has a mean of 2.727. The mean illiquidity (ILLIQ) and Bid-ask spread (Bid-Ask) are 0042 and 16.14% respectively.

Table 2 presents the correlation between idiosyncratic volatility and environmental information disclosure, along with control variables. Univariate analysis indicates a negative relationship between idiosyncratic volatility and environmental disclosure when other effects are not controlled. Additionally, the correlations between the control variables and idiosyncratic volatility are significant, underscoring the necessity of controlling for these factors.

3.4. Empirical models

3.4.1. Environmental disclosure and idiosyncratic volatility

To investigate the correlation between environmental disclosure and stock-specific volatility, the following panel data regression model, as shown in Equation (3), is examined:

$$IV_{i,t} = \delta_0 + \delta_1 ENVD_{i.t} + \delta_2 RET_{i,t} + \delta_3 ROA_{i,t} + \delta_4 SIZE_{i,t} + \delta_5 LEV_{i,t} + \delta_6 BM_{i,t} + \delta_7 INS_{i,t} + \delta_8 AGE_{i,t} + \sum Year\ FE + \sum Firm\ FE + \varepsilon_{i,t} \quad (3)$$

The subscripts i and t denote the indices of company and year, respectively. IV represents the dependent variable, idiosyncratic volatility. ENVD is the environmental disclosure score.

3.4.2. The impact of energy type and environmental disclosure on idiosyncratic volatility

To test Hypothesis 2, a dummy variable for energy type ((Rnew)) is introduced. The data source for the (Rnew) dummy variable, which indicates whether a company is classified as a renewable energy firm, is the Refinitiv database. Refinitiv categorizes companies into different sectors based on the TRBC (Thomson Reuters Business Classification) Economic Sector Codes. Specifically, the code 5010 is used for fossil fuel companies, and the code 5020 is used for renewable energy companies. These classifications were used to create the (Rnew) dummy variable, where a value of 1 indicates that the company is a renewable energy firm (TRBC code 5020), and a value of 0 indicates that the company is a fossil fuel firm (TRBC code 5010). An interaction term between the dummy variable and (ENVD) is added in the following equation (4), which is expected to have a significant impact on the relationship between environmental information disclosure and idiosyncratic volatility.

$$IV_{i,t} = \delta_0 + \delta_1 ENVD_{i.t} + \delta_2 Rnew_{i.t} + \delta_3 Rnew_{i.t} * ENVD_{i.t} + \delta_4 RET_{i,t} + \delta_5 ROA_{i,t} + \delta_6 SIZE_{i,t} + \delta_7 LEV_{i,t} + \delta_8 BM_{i,t} + \delta_9 INS_{i,t} + \delta_{10} AGE_{i,t} + \sum Year\ FE + \sum Firm\ FE + \varepsilon_{i,t} \quad (4)$$

3.4.3. Environmental disclosure and information asymmetry

We use the models suggested by Baron and Kenny (1986) to test whether there is a mediating effect of information asymmetry between environmental disclosure and idiosyncratic volatility. Hence, the following models are used to assess the hypothesis 3:

$$IA^k_{i,t} = \delta_0 + \delta_1 ENVD_{i.t} + \delta_2 RET_{i,t} + \delta_3 ROA_{i,t} + \delta_4 SIZE_{i,t} + \delta_5 LEV_{i,t} + \delta_6 BM_{i,t} + \delta_7 INS_{i,t} + \delta_8 AGE_{i,t} + \sum Year\ FE + \sum Firm\ FE + \varepsilon_{i,t} \quad (5)$$

$$IV_{i,t} = \delta_0 + \delta_1 IA^k_{i,t} + \delta_2 ENVD_{i.t} + \delta_3 RET_{i,t} + \delta_4 ROA_{i,t} + \delta_5 SIZE_{i,t} + \delta_6 LEV_{i,t} + \delta_7 BM_{i,t} + \delta_8 INS_{i,t} + \delta_9 AGE_{i,t} + \sum Year\ FE + \sum Firm\ FE + \varepsilon_{i,t} \quad (6)$$

$IA^k_{i,t}$ is the proxy of information asymmetry, where k represents either the illiquidity measure or bid-ask spread. Other variables are consistent with those in Equation (3)

4. Empirical results

4.1. Environmental disclosure and idiosyncratic volatility

In Column (1) of Table 3, the results show that environmental disclosure is significantly and positively correlated with idiosyncratic volatility. This finding supports Hypothesis 1, indicating that increased environmental disclosure by energy companies amplifies the idiosyncratic volatility of their stock returns. The positive correlation suggests that heightened transparency around environmental practices and associated risks generates greater uncertainty among investors about these firms' future performance. This outcome may be attributed to the increased awareness of "carbon risks" and the potential for regulatory or market penalties for poor environmental performance. Furthermore, environmental disclosures prompt investors to reassess the long-term sustainability and risk profiles of these firms, resulting in more volatile stock prices.

This observation aligns with prior studies, which highlight the role of environmental risks in shaping investor sentiment and stock performance (Alok et al. 2020; Anderson and Robinson 2019; Bessec and Fouquau 2020; Choi et al. 2020; Fiordelisi et al. 2020; Ilhan et al. 2021; Makridis 2018; Wu and Lu 2020). Such findings underscore the importance of environmental risks in influencing investor behavior and highlight the significance of environmental disclosures in financial markets. From the perspective of *Legitimacy Theory*, these results suggest that disclosures aimed at maintaining legitimacy may unintentionally introduce investor uncertainty, thereby increasing idiosyncratic volatility. However, this result contrasts with Benlemlih et al. (2018), who reported a negative relationship between environmental disclosure and idiosyncratic volatility. The discrepancy may stem from differences in sample composition. Benlemlih et al.'s study included a broad range of industries, whereas our analysis focuses exclusively on the energy sector, which is particularly sensitive to environmental risks. The energy sector's heightened exposure to environmental liabilities may amplify the perceived risks, leading to increased volatility compared to more diversified industrial samples.

4.2. Joint effects of environmental disclosure and energy type on the idiosyncratic volatility

Column (2) of Table 3 examines the relationship between environmental disclosure and idiosyncratic volatility for different energy types, as outlined in Hypothesis 2. The results

Table 3. Regression results of environmental information disclosure on idiosyncratic volatility.

	(1)	(2)
	IV	IV
ENVD	0.155**	0.272**
	(2.20)	(2.54)
Rnew		−2.557
		(−0.67)
ENVD*Rnew		−0.266*
		(−1.77)
RET	9.039***	8.831***
	(5.22)	(5.47)
ROA	−30.328*	−33.051**
	(−1.99)	(−2.06)
SIZE	0.61	0.975
	(0.33)	(0.61)
LEV	−3.00	0.086
	(−0.34)	(0.01)
BM	−0.007***	−0.007***
	(−2.82)	(−3.41)
INS	0.203***	0.196***
	(3.69)	(3.35)
AGE	17.941**	17.436**
	(2.32)	(2.00)
Constant	−24.85	−29.21
	(−0.68)	(−0.88)
Year FE	Yes	Yes
Firm FE	Yes	Yes
N	311	311
R^2	0.594	0.711

T-statistics are in parentheses below each variable. ***, ** and * indicate significant levels at 1%, 5% and 10%, respectively.

reveal a clear divergence based on the energy type. For fossil fuel companies, increased environmental disclosure amplifies idiosyncratic volatility. This effect can be attributed to heightened investor concerns over the environmental risks and regulatory pressures associated with these firms. In contrast, for renewable energy companies, increased environmental disclosure reduces idiosyncratic volatility by signaling lower carbon risk and fostering positive investor perceptions.

This finding highlights how Legitimacy Theory applies differently to firms depending on their energy type. For fossil fuel companies, environmental disclosures may expose significant environmental liabilities and compliance risks, amplifying investor concerns and eroding firm legitimacy. On the other hand, renewable energy firms benefit from environmental disclosures as these are perceived as reinforcing their legitimacy and commitment to sustainability, thereby reducing investor uncertainty. This distinction underscores the heterogeneity of legitimacy effects across different energy types. Moreover, the strategic transition of fossil fuel companies toward renewable energy provides further insights into the implications of Legitimacy Theory. By diversifying their energy portfolios to include more sustainable options, fossil fuel companies can mitigate their exposure to regulatory penalties and environmental risks. As Gatfaoui (2015) suggests, firms' ability to adapt their energy strategies plays a crucial role in reducing perceived risks and stabilizing stock performance. As more fossil fuel companies shift toward renewable energy, the overall risk profile of the energy sector may improve, leading to a decrease in idiosyncratic volatility.

4.3. The mediating effect of information asymmetry

Table 4 presents the results of the mediating effect of information asymmetry on the relationship between environmental disclosure and idiosyncratic volatility. Column (1) and Column (3) show no significant relationship between environmental disclosure and the illiquidity measure (ILLIQ) or the bid-ask spread. Similarly, the coefficients for information asymmetry proxies (ILLIQ and Bid-Ask) in Column (2) and Column (4) are also not significant. These findings suggest that information asymmetry does not act as a channel through which environmental disclosure influences idiosyncratic volatility. The results imply that the transparency provided by environmental disclosures is sufficiently high to mitigate the manipulation of information, thereby preventing increased idiosyncratic volatility caused by information asymmetry.

One possible explanation lies in the regulatory framework established by the State Environmental Protection Ministry of China (SEPMC). Since September 2010, SEPMC has mandated that China's most heavily polluting industrial sectors disclose their pollutant emissions annually and demonstrate compliance with environmental regulations (Fonseka, Rajapakse, and Tian 2019; Zhongfu et al., 2011). This legislation enforces a baseline level of transparency and accountability, limiting the scope for firms to obscure their environmental behavior. Fossil fuel energy companies, in particular, are compelled to provide full and accurate disclosures under this regulatory regime, effectively reducing the potential for information asymmetry.

For renewable energy companies, the incentives for transparent environmental disclosure are market-driven rather than solely regulatory. Managers of renewable energy firms are less likely to engage in "greenwashing" strategies and are more motivated to provide comprehensive disclosures to enhance their reputations (Bewley and Li 2000; Clarkson et al. 2008). Transparent reporting on environmental practices not only bolsters their credibility but also differentiates them in the market, attracting investment and aligning with growing investor preferences for sustainability. Chaklader and

Table 4. The mediating effect of information asymmetry.

	(1)	(2)	(3)	(4)
	ILLIQ	IV	Bid-Ask	IV
ENVD	−0.000	0.1474**	−0.059	0.1583**
	(−0.28)	(2.03)	(−1.08)	(2.11)
ILLIQ		−528.90		
		(−1.59)		
Bid-Ask				0.0636
				(0.47)
RET	0.001**	9.5626***	3.582***	9.2707***
	(2.27)	(5.46)	(3.82)	(5.44)
ROA	0.003	−28.9031*	−1.531	−34.0817**
	(1.00)	(−1.88)	(−0.31)	(−2.13)
SIZE	−0.004***	−1.1107	−8.783***	1.2333
	(−4.28)	(−0.45)	(−7.09)	−0.54
LEV	0.000	−3.1943	18.589***	−4.2119
	(0.24)	(−0.38)	(3.38)	(−0.46)
BM	−0.000	−0.0076***	−0.001	−0.0066***
	(−1.61)	(−3.14)	(−0.28)	(−2.78)
INS	0.000**	0.2223***	0.135**	0.1873***
	(2.21)	(3.71)	(2.39)	(3.33)
AGE	0.001	19.1483**	−3.398	20.3462**
	(0.72)	(2.46)	(−0.29)	(2.68)
Constant	0.057***	1.9595	158.604***	−40.2919
	(4.33)	(0.04)	(4.25)	(−0.97)
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
N	307	303	310	303
R^2	0.429	0.6031	0.590	0.6024

T-Statistics are in parentheses below each variable. ***, ** and * and indicate significant levels at 1%, 5% and 10%, respectively.

Gulati (2015) similarly found that firms with environmental certifications are more likely to demonstrate their environmental practices, reinforcing the credibility of their disclosures and reducing information asymmetry.

This theoretical distinction ties closely to *Legitimacy Theory*, which posits that environmental disclosures can stem from either genuine transparency-driven motives or opportunistic, symbolic behaviors. Our findings contribute to this theory by demonstrating that symbolic disclosures, which lack substantive environmental actions, do not apply in this context. Regulatory requirements for fossil fuel companies and reputational incentives for renewable energy firms ensure that disclosures are substantive and transparent, rather than opportunistic.

Overall, our results do not support the managerial opportunism theory, which assumes that managers selectively disclose environmental information to create an appearance of compliance while hiding underlying risks (Gray 2010). Instead, the findings indicate that regulatory pressures for fossil fuel companies and market-driven incentives for renewable energy firms encourage comprehensive and authentic disclosures. This transparency mitigates the potential for information asymmetry and its impact on idiosyncratic volatility.

4.4. Robustness checks

To evaluate the robustness of the nexus between environmental disclosure and idiosyncratic volatility, a series of additional tests were conducted to address alternative hypotheses and model specifications.

First, the regression procedure was repeated using alternative proxies for the dependent variable. Instead of idiosyncratic volatility, we employed total volatility, which includes both systematic and idiosyncratic risk, as an alternative measure (Benlemlih et al. 2018; Bouslah, Kryzanowski, and M'zali 2013). Additionally, we utilized the Fama and French's (2015) five-factor model to compute idiosyncratic volatility, as specified below:

$$r_{i,d} = \alpha_i + \beta_i r_{m,d} + h_i HML + s_i SMB + r_i RMW + c_i CMA + u_i \tag{7}$$

Where RMW (Robust minus Weak) is the return of high and low profitability companies; CMA (Conservative minus Aggressive) refers to the difference between the returns of the low and high investment companies.

Second, to address concerns about reverse causality, we re-estimated Equation (3) with an alternative specification, where the environmental disclosure score from the prior year was used to predict the current year's idiosyncratic volatility. This approach allowed us to assess whether lagged environmental disclosure has a consistent effect on idiosyncratic volatility.

Third, to address potential endogeneity and omitted variable bias that could affect the causal relationship between environmental disclosure and idiosyncratic volatility, we adopted the two-stage least squares (2SLS) regression model with instrumental variables. The chosen instrumental variables were the province average score and industry average score for environmental disclosure. These scores were calculated based on the environmental disclosure data of all Chinese listed firms in the Bloomberg database. Specifically, the province average score reflects the environmental disclosure practices of firms located in the same province as the target firm, which are likely influenced by local government environmental policies. The industry average score reflects the environmental disclosure practices of firms within the same industry, as classified by the Chinese Securities Exchange Commission, which are likely shaped by industry norms and competitive pressure. These instrumental variables are expected to be correlated with a firm's environmental disclosure score because a firm's disclosure practices are influenced by both local government environmental policies and the pressure exerted by industry peers (El Ghoul et al. 2011; Eliwa, Aboud, and Saleh 2021; Kim, Li, and Li 2014). At the same time, these variables are unlikely to directly affect idiosyncratic volatility, as the latter reflects firm-specific information. Therefore, the exogeneity condition of the instrumental variables is likely to hold.

The results of the robustness checks are presented in Table 5. Columns (1) and (2) report the findings using alternative dependent variables, namely total volatility and idiosyncratic volatility calculated using the Fama and French (2015) five-factor model, respectively. In both cases, environmental disclosure remains significantly and positively correlated with these measures of volatility. These results align with the primary analysis, reinforcing the robustness of the positive relationship between environmental disclosure and idiosyncratic volatility.

To address concerns regarding reverse causality, we incorporate lagged environmental disclosure scores in Columns (3) and (4). The results show that both one-year and two-year lagged environmental disclosure scores positively and significantly affect the current year's idiosyncratic volatility. This provides strong evidence that the direction of causality flows from environmental disclosure to idiosyncratic volatility, rather than the reverse.

Column (5) presents the results of the two-stage least squares (2SLS) regression, where province-level and industry-level average environmental disclosure scores are used as instrumental variables. The results indicate that environmental disclosure remains significantly and positively correlated with idiosyncratic volatility. Statistical tests validate the relevance and exogeneity of the instrumental variables. The Kleibergen-Paap statistics confirm that the instruments are not under-identified, while the Cragg-Donald Wald F statistics indicate that the instruments are not weak. Additionally, the Hansen J statistics verify that the models are not over-identified, further ensuring the validity of the instruments. These findings suggest that endogeneity is unlikely to drive the observed relationship between environmental disclosure and idiosyncratic volatility.

To further address causality concerns, we employ the Propensity Score Matching (PSM) method, following Rosenbaum and Rubin (1983) and W. Luo et al. (2019). Firms are categorized into two groups based on the annual median environmental disclosure score: firms with scores above the median are assigned to the high-level disclosure group, while those below the median belong to the low-level disclosure group. Using a Logit regression with all independent variables

Table 5. Robustness checks.

	(1)	(2)	(3)	(4)	(5)
	Total volatility	Five-factor model	Lag1	Lag2	2SLS-IV regression
ENVD	0.011*	0.145**	0.140*	0.225**	0.607**
	(1.730)	(2.140)	(1.81)	(2.69)	(1.960)
RET	0.565***	9.083***	8.682***	7.435***	9.389***
	(4.370)	(5.290)	(4.60)	(4.02)	(5.650)
ROA	−2.460*	−27.225*	−19.761	−11.409	−29.874**
	(−1.80)	(−1.88)	(−1.26)	(−0.63)	(−1.97)
SIZE	0.290*	0.782	1.575	2.762	−1.284
	(1.690)	(0.440)	(0.70)	(0.91)	(−0.62)
LEV	−0.395	−6.743	−1.388	−4.596	−4.562
	(−0.63)	(−0.77)	(−0.14)	(−0.47)	(−0.52)
BM	−0.0004**	−0.006**	−0.006**	−0.008***	−0.009***
	(−2.36)	(−2.68)	(−2.63)	(−3.01)	(−3.54)
INS	−0.002	0.192***	0.171**	0.153	0.222***
	(−0.31)	(3.680)	(2.24)	(1.49)	(3.550)
AGE	1.600**	16.054**	32.075**	45.895**	17.686**
	(2.350)	(2.100)	(2.63)	(2.64)	(2.160)
Constant	−5.985*	−22.794	−84.364*	−128.759*	
	(−1.97)	(−0.64)	(−1.72)	(−1.69)	
Year FE	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
N	309	311	272	235	308
R^2	0.769	0.592			0.549
Kleibergen-Paap Under. (p)					0.0003
Cragg-Donald Wald F statistic					11.306
Hansen J Statistic Overid (p)					0.519

t-Statistics are in parentheses below each variable. ***, **and * and indicate significant levels at 1%, 5% and 10%, respectively.

Table 6. PSM (propensity score matching) results.

Variable	Unmatched Matched	Mean Treated	Mean Control	T test t	T test P>|t|
Panel A: Balancing test of PSM					
RET	U	0.07236	0.12239	-0.48	0.630
	M	0.06047	0.11674	-0.79	0.429
ROA	U	0.03284	0.01737	2.36	0.019
	M	0.0266	0.03597	-1.57	0.118
Size	U	17.488	16.099	11.54	0.000
	M	16.655	16.755	-0.93	0.356
LEV	U	0.10853	0.06539	5.28	0.000
	M	0.09716	0.09104	0.46	0.648
BM	U	1022.1	716.28	5.29	0.000
	M	850.06	856.66	-0.08	0.935
INS	U	72.065	58.456	5.66	0.000
	M	63.52	65.014	-0.45	0.650
AGE	U	2.7514	2.752	-0.02	0.983
	M	2.7711	2.688	1.59	0.114

Variables	Treated	Controls	Difference	S.E.	t-statistics
Panel B: PSM estimator					
IV	35.270	31.270	4.000	1.862	2.150***

Panel C: Results Based on the Matched Sample	(1)
ENVD	0.224**
	(2.26)
RET	9.786***
	(5.36)
ROA	-39.320***
	(-2.75)
SIZE	3.880*
	(1.69)
LEV	5.071
	(0.47)
BM	-0.004
	(-1.32)
INS	0.241***
	(2.99)
AGE	11.996
	(0.88)
_cons	-68.22
	(-1.39)
Year FE	Yes
Firm FE	Yes
N	220
r2	0.668

t-Statistics are in parentheses below each variable. ***, **and * and indicate significant levels at 1%, 5% and 10%, respectively.

from Equation (3), each firm in the high-level disclosure group is matched with a control firm from the low-level disclosure group using nearest-neighbor one-to-one matching within a caliper distance of 0.01 in propensity scores. This matching process yields 220 firm-year observations.

Table 6 provides the results of the PSM analysis. Panel A presents the balance test, which shows that most t-tests fail to reject the null hypothesis, confirming that the treatment and control groups are statistically balanced. Panel B reports the average treatment effect (ATT), demonstrating that high-level disclosure firms exhibit significantly higher idiosyncratic volatility than low-level disclosure firms. Panel C presents the regression results for the matched sample, which confirm the robustness of our primary findings. Environmental disclosure continues to show a significant positive association with idiosyncratic volatility in the Chinese energy sector. Overall, the robustness checks validate the

consistency and reliability of our findings across various model specifications and alternative methodologies. The positive relationship between environmental disclosure and idiosyncratic volatility persists, demonstrating the robustness of this key insight.

5. Conclusion

This study examines the impact of environmental disclosure on the idiosyncratic volatility of expected stock returns for companies operating in China's energy sector. Utilizing the Fama and French three-factor model to derive idiosyncratic volatility and environmental disclosure scores extracted from the Bloomberg database for the period 2011 to 2020, the study uncovers a significant positive relationship between environmental disclosure and idiosyncratic volatility. This relationship is robust across a series of methodological tests. Additionally, the findings reveal that the environmental disclosures of renewable energy companies significantly weaken this positive relationship, while fossil fuel energy companies exhibit a greater impact on idiosyncratic volatility. Importantly, the study rules out the possibility that environmental disclosure scores act as a source of noise in the stock market, even within China's mixed system of mandatory and voluntary disclosure. These results suggest that investors act rationally, primarily focusing on risks related to the polluting nature of the energy sector. Furthermore, the evidence indicates that the Chinese government has effectively regulated environmental disclosure in heavily polluting industries, mitigating concerns of "under-disclosure" and "greenwashing," and thereby eliminating the influence of information asymmetry in environmental disclosure.

From the perspective of *Legitimacy Theory*, this study provides new insights into how environmental disclosures, aimed at maintaining or enhancing corporate legitimacy, can paradoxically lead to increased investor concerns. For fossil fuel energy companies, environmental disclosures amplify attention to their polluting nature, raising perceived risks and contributing to higher idiosyncratic volatility. Conversely, for renewable energy companies, disclosures reinforce their environmental responsibility and legitimacy, reducing uncertainty and stabilizing stock performance. This contrast highlights the heterogeneous effects of legitimacy-driven disclosures across different energy types and underscores the nuanced role that legitimacy plays in shaping investor perceptions and financial outcomes.

Our findings offer valuable insights for regulators, energy companies, and investors. First, given the lack of standardized environmental disclosure procedures for most Chinese companies, our results highlight the importance of existing environmental disclosure regulations for polluting industries and their broader implications for other sectors. Strengthening and standardizing environmental disclosure frameworks across all industries would benefit regulatory authorities and enhance the transparency and comparability of environmental practices in China. Second, traditional energy companies should focus on adopting new business models, such as transitioning to low-carbon energy sources and advancing technological innovations, to better manage their carbon-related risks and achieve a sustainable competitive advantage. Such initiatives not only mitigate risks but also align with the growing investor demand for responsible investments. The relationship between environmental disclosure and idiosyncratic volatility underscores the importance of incorporating energy stocks into diversified portfolios for investors seeking to balance financial returns with environmental considerations.

Finally, while this study relies on environmental disclosure data from a specialized database widely used in finance and economics research, future researchers are encouraged to collect raw data from corporate disclosures to manually construct disclosure indices that more precisely measure companies' environmental disclosure practices. This approach would offer a complementary perspective to standardized databases. Moreover, future research could extend the scope of inquiry to unlisted energy companies in China, which remain underexplored in the literature. Investigating the motivations and disclosure practices of these firms could provide a richer understanding of environmental disclosure dynamics in the energy sector.

Disclosure statement

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Author contributions

CRediT: **Xin Yang:** Conceptualization, Data curation, Software, Writing – original draft; **Ahmad F.S. Hassan:** Methodology, Resources; **Yusuf Karbhari:** Supervision, Writing – review & editing.

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Appendix

Table A1. Variable definitions.

Variable	Definitions	Data Source
IV	Idiosyncratic volatility. Annualized standard deviation of the residual from the Fama-French three-factor model.	CSMAR
ENVD	Environmental disclosure score	Bloomberg
RET	The annual buy-and-hold return at the fiscal year-end;	CSMAR
ROA	Return on asset: Net income divided by total assets	CSMAR
SIZE	Firm size: The nature log of total asset	CSMAR
LEV	Leverage: The ratio of total liabilities to total assets	CSMAR
BM	Book to market ratio: The ratio of total assets to market value	CSMAR
INS	Institutional ownership: The percentage of stocks held by institutional investors	CSMAR
AGE	Firm age: the nature log of 1 plus the number of years since the firm first listed	CSMAR
ILLIQ	Stock illiquidity measure: year average value of daily absolute return divided by Chinese Yuan (CNY) trading volume of the respective day, and then multiplied by 10^7	WIND
Bid-Ask	Bid-ask spread: [(Ask-Bid)/((Ask+Bid)/2)]*100	WIND
Rnew	The dummy variable of energy type: it has a value of 1 if the company is a renewable energy company and 0 for fossil fuel firms	Refinitiv Eikon

Table A2. The detailed components of the bloomberg environmental disclosure.

Topic	Field Description
Air Quality	**Air Quality Disclosure Score**
Air Quality	Nitrogen Oxide Emissions
Air Quality	VOC Emissions
Air Quality	Carbon Monoxide Emissions
Air Quality	Particulate Emissions
Air Quality	Sulphur Dioxide/Sulphur Oxide Emissions
Climate Change	**Climate Change Disclosure Score**
Climate Change	Emissions Reduction Initiatives
Climate Change	Climate Change Policy
Climate Change	Climate Change Opportunities Discussed
Climate Change	Risks of Climate Change Discussed
Climate Change	Direct CO2 Emissions
Climate Change	Indirect CO2 Emissions
Climate Change	ODS Emissions
Climate Change	GHG Scope 1
Climate Change	GHG Scope 2
Climate Change	GHG Scope 3
Climate Change	Scope 2 Market Based GHG Emissions
Climate Change	Scope of Disclosure
Climate Change	Carbon per Unit of Production
Ecological & Biodiversity Impacts	**Ecological & Biodiversity Impacts Disclosure Score**
Ecological & Biodiversity Impacts	Biodiversity Policy
Ecological & Biodiversity Impacts	Number of Environmental Fines
Ecological & Biodiversity Impacts	Environmental Fines (Amount)
Ecological & Biodiversity Impacts	Number of Significant Environmental Fines
Ecological & Biodiversity Impacts	Amount of Significant Environmental Fines
Energy	**Energy Disclosure Score**
Energy	Energy Efficiency Policy
Energy	Total Energy Consumption
Energy	Renewable Energy Use
Energy	Electricity Used
Energy	Fuel Used – Coal/Lignite
Energy	Fuel Used – Natural Gas
Energy	Fuel Used – Crude Oil/Diesel
Energy	Self Generated Renewable Electricity
Energy	Energy Per Unit of Production
Materials & Waste	**Materials & Waste Disclosure Score**
Materials & Waste	Waste Reduction Policy
Materials & Waste	Hazardous Waste
Materials & Waste	Total Waste
Materials & Waste	Waste Recycled
Materials & Waste	Raw Materials Used
Materials & Waste	% Recycled Materials
Materials & Waste	Waste Sent to Landfills
Materials & Waste	Percentage Raw Material from Sustainable Sources
Supply Chain	**Supply Chain Disclosure Score**
Supply Chain	Environmental Supply Chain Management
Water	**Water Disclosure Score**
Water	Water Policy
Water	Total Water Discharged
Water	Water per Unit of Production
Water	Total Water Withdrawal
Water	Water Consumption