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# Economic vulnerabilities and sustainability in energy utilities: Managing climate change in the face of geopolitical turmoil

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A R T I C L E I N F O

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A B S T R A C T

This study investigates the implications of climate change on the environmental management strategies adopted by Chinese energy utility companies over the period from 2008 to 2021. The study highlights that an increase in temperatures correlates with a greater likelihood of these firms implementing environmental management strategies. This tendency is particularly pronounced among companies characterized by lower revenue levels, elevated operational costs, increased media scrutiny, or a comparatively weaker commitment to social responsibilities. Additionally, the analysis reveals that improved carbon performance mitigates this effect, whereas state ownership amplifies the observed trends. This research contributes to understanding the dynamic interplay between climate change and corporate environmental strategy within the context of Chinese energy utilities.

## 1. Introduction

Escalating geopolitical conflicts, exemplified by the Russo-Ukrainian War, have had profound impacts on global energy supplies, sparking widespread concerns about energy security (Goodell et al., 2023). As renewable energy sources are yet to fully replace traditional energy resources, nations are enhancing the resilience of their energy infrastructures by increasing their strategic reserves of conventional energies (Goodell et al., 2023; Liang et al., 2024). Such strategies, while addressing geopolitical risks, inadvertently lead to a rise in global fossil fuel consumption, thus increasing greenhouse gas emissions and intensifying existing environmental and climate crises (Zhao et al., 2023). Energy utility firms, which are central to the production, supply, and distribution of energy, are under considerable pressure to meet the public's increasing demands for both energy reliability and environmental sustainability.

Prior research on environmental management strategies in energy utility firms has largely concentrated on corporate characteristics, stakeholder influences, and regulatory policies (Meyer and Pac, 2013; Peterson, 2022; Scott et al., 2019; Thompson et al., 2020). These studies typically found that the primary motivation for adopting such strategies was to buffer against negative shocks, often neglecting the role of climate change. Given their government-mandated responsibilities and the critical nature of their operations, which include managing electricity grids, gas pipelines, and heating and cooling systems, energy utility firms are particularly vulnerable to the effects of climate change. Faced with the challenges of maintaining supply chain stability, complying with regulatory demands, and managing stakeholder scrutiny amidst increasing climate volatility (Clark et al., 2023; Cormier and Magnan, 2015; Liu

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et al., 2022), these firms are compelled to adopt robust environmental management strategies to mitigate the impacts of climate change.

To address this research gap, this study examines the influence of climate change on the adoption of environmental management strategies by energy utility firms. We explore the direct impacts of climate change, examining elements such as supply costs, governmental regulations, and stakeholder concerns on a firm's strategic responses. Additionally, we investigate the moderating effects of government ownership and corporate carbon performance. Government ownership plays a crucial role in enhancing a firm's ability to manage environmental governance, secure financial resources, and meet stakeholder expectations in the context of climate change. Conversely, corporate carbon performance indicates a firm's dedication to environmental practices. By evaluating these moderating factors, our research elucidates critical drivers that motivate energy utility companies to implement strategies addressing climate change.

This study makes significant contributions in three aspects. First, while previous studies have acknowledged the vulnerability of energy utility firms to climate change, they have not fully captured the complex interplay between climate change and the environmental strategies these firms adopt. Our study advances the existing body of knowledge by specifically examining how climate change influences the environmental management practices of these firms. Second, we explore the roles of government ownership and corporate carbon performance in shaping responses to climate change, providing a detailed examination of how these internal factors affect the environmental management strategies of energy utility firms from the perspectives of ownership structure and environmental capabilities. Lastly, our research provides a comprehensive classification of firms based on costs, revenues, media exposure, and social responsibility commitments. Through meticulous and extensive robustness checks, we ensure the integrity of our findings and offer a detailed analysis of potential firm-specific variations, thereby deepening our understanding of this complex topic.

The rest of the paper is organised as follows: Section 2 elaborates on the theory and hypothesis development; Section 3 delineates our research methodology; Section 4 presents the results of the data analysis; and Section 5 discusses the findings. Section 6 presents the conclusion, implications and limitations of the study. Five encapsulates the discussion and conclusion.

## 2. Theory and hypothesis development

### 2.1. Impact of climate change on firms

Global warming has intensified climate instability worldwide, presenting substantial challenges for businesses. The literature has extensively discussed the impact of climate change on business operations through various climate events such as temperature fluctuations, heatwaves, cold spells, heavy rains, floods, storms, droughts, and more (Tang et al., 2023; Yu et al., 2023). The effects of climate change on businesses manifest through two primary pathways. Firstly, direct effects include disruptions to production efficiency and operational capabilities, which can alter the balance between a company's revenue and operating costs, necessitating strategic adaptations (Barrot and Sauvagnat, 2016; Huynh and Xia, 2021; Linnenluecke et al., 2011; Pankratz et al., 2019). Secondly, indirect pressures arise from stakeholders such as governments and international organizations that demand reductions in carbon emissions and stronger environmental protections, placing firms under significant regulatory and compliance pressures (He et al., 2022; Hu et al., 2022). Investors and the public also expect firms to uphold social responsibilities, which prompts firms to enhance their environmental performance and transparency as a way to mitigate these pressures and demonstrate their commitment to environmental management (Li et al., 2023; Safiullah et al., 2022). Overall, climate change has reshaped both the internal and external environments of businesses, compelling them to devise and implement adaptive strategies to mitigate vulnerabilities associated with these changes (Gasbarro and Pinkse, 2016).

### 2.2. Climate change and the environmental management strategy of energy utilities

Climate change influences the adoption of environmental management strategies by energy utility firms primarily through rising supply costs. Extreme weather events and natural disasters, which are becoming more frequent due to climate change, make it more difficult to access, convert, and transport energy (Schaeffer et al., 2012). For example, disruptions to critical infrastructure, such as oil and gas pipelines and electricity transmission lines, will increase maintenance and replacement costs. Additionally, the cost of resource inputs critical to the energy sector—including coal, electricity, oil, natural gas, and water—as well as the pricing of energy products, are often regulated by governments (Beecher and Kalmbach, 2013; Boute and Fang, 2022; Clark et al., 2023; Yang et al., 2021). Consequently, utility firms are unable to simply adjust product prices to offset rising costs. To manage these costs and maintain sustainable operations, these firms are motivated to shift towards more environmentally sustainable energy sources and technologies. This shift not only reduces resource consumption but also enhances energy efficiency, aligning economic with environmental goals.

Secondly, climate change motivates regional governments to enact stricter policies aimed at curbing carbon emissions and fostering sustainable energy practices. These policies may include emissions caps, carbon taxes, carbon pricing mechanisms, environmental monitoring, and environmental impact assessments (Clark et al., 2023; Ding and Hu, 2022; Jiang et al., 2022; Liu et al., 2022). In response, energy companies are required to adopt environmental management strategies that could involve reducing pollutant emissions, increasing the proportion of renewable energy, and improving energy efficiency (Cardoso et al., 2023). For example, Kim and Bae (2022) observed that South Korea's carbon pricing initiative encouraged the electricity sector to reduce reliance on fossil fuels and shift towards less carbon-intensive energy sources. Similarly, Tang et al. (2019) reported that the implementation of ultra-low emissions standards in China led to significant reductions in SO2, NOx, and particulate matter emissions in the electricity sector between 2014 and 2017. Based on these observations, we hypothesize that stricter governmental environmental regulations prompted by climate change concerns will compel utility firms to implement more comprehensive environmental management strategies.

Lastly, climate change increases the scrutiny of corporate environmental performance by regulatory bodies, investors, and a diverse range of stakeholders (Safiullah et al., 2022). These stakeholders urge companies to adopt more proactive environmental management practices. By taking such proactive steps, firms can minimize the need for external regulation and more readily gain the approval of their stakeholders (Testa et al., 2018). Therefore, we argue that as climate change continues to evolve, utility companies are likely to demonstrate their commitment to environmental improvement by implementing environmental management strategies in response to these stakeholder concerns. Thus, we propose the following hypothesis:

**Hypothesis 1**. Climate change is positively related to the adoption of environmental management strategies by energy utility firms.

### 2.3. Role of firm carbon performance

In the current literature, carbon performance is typically viewed as beneficial, offering societal advantages through reduced resource consumption and lessened environmental impact (Atif et al., 2023; Wang et al., 2020). However, this paper challenges the assumption by suggesting that high carbon performance may actually reduce the urgency for utility firms to adopt environmental management strategies in the face of climate change. This counterintuitive effect can be explained by two primary reasons:

Firstly, firms with superior carbon performance often demonstrate higher energy efficiency and make use of advanced equipment, technology and management practices (Liang et al., 2024). This efficiency allows them to produce more with fewer resources (Trinks et al., 2020), which can mitigate the increased supply costs resulting from climate anomalies. This capability implies that firms with high carbon performance can maintain stable energy supplies at lower operational costs, even under challenging climate conditions. Furthermore, there is evidence that excellent carbon performance can also bolster a firm's financial outcomes (Bolton and Kacperczyk, 2023; Busch and Lewandowski, 2018; Siddique et al., 2021), enhancing their capacity to address climate change effectively without needing additional environmental strategies.

Secondly, a high level of carbon performance may suggest that a utility firm has already implemented significant adaptations to mitigate climate change. Carbon performance not only reflects a firm's operational efficiencies but also its strategic approach to managing carbon outputs proactively (Wang et al., 2021). Firms with strong carbon performance often engage in extensive environmental disclosure, enhancing their market image by demonstrating social responsibility through emissions reductions and pollution control (Li et al., 2022; Qian and Schaltegger, 2017; Siddique et al., 2021). As such, utility firms with established high carbon performance may feel that their existing efforts suffice, thus seeing less incentive to further enhance their environmental management strategies in response to ongoing climatic challenges. Thus, we propose the following hypothesis:

**Hypothesis 2**. Firm carbon performance weakens the positive relationship between climate change and energy utilities adopting environmental management strategies.

### 2.4. Role of state background

As global consensus on environmental issues strengthens, governments have increasingly focused on addressing climate change. In China, the government combats climate change through direct interventions in corporate operations, including environmental regulations, emission standards, financing constraints, pollution charges and taxation (He et al., 2022; Hu et al., 2022; Zhang et al., 2021). Additionally, the government indirectly influences corporate behavior by holding shares in companies, thereby advancing environmental management objectives (Wang et al., 2023; Zhang, 2017). This dual approach heightens the commitment of utility firms to climate change initiatives and enhances their ability to implement environmental management strategies.

Firstly, government ownership compels firms to align their operations with political and social objectives rather than purely profit-driven goals. Unlike private firms, which focus on maximizing shareholder wealth, state-owned enterprises (SOEs) pursue broader objectives like price stabilization, employment generation, and controlling key industries (Huang et al., 2021). These firms are often more prepared to undertake risks associated with new environmental policies. As the government places a high priority on addressing climate concerns, SOEs tend to demonstrate a stronger commitment to environmental goals (Calza et al., 2016). Consequently, SOEs are more likely to embrace environmental management strategies to support sustainable energy development and reduce carbon emissions.

Secondly, government ownership often means that firms have access to significant resources that facilitate the implementation of environmental management strategies. SOEs are more likely to benefit from government favors such as favorable credit policies and easier IPO approvals (Cheng et al., 2020; Francis et al., 2009; Zhang et al., 2021), which alleviate financial constraints and boost their ability to adopt robust environmental practices. Thus, government connections effectively lower the economic barriers to implementing environmental management.

Lastly, government ownership subjects firms to heightened public scrutiny. Social media and public opinion often hold SOEs to higher standards of social responsibility than their private counterparts (Tang et al., 2020). Consequently, government-owned utility firms face greater pressure to adopt environmental management strategies, not only to comply with regulatory expectations but also to maintain a favorable public image and gain trust. Overall, government ownership significantly influences how utility firms manage environmental challenges, providing both the means and the incentive to enhance their environmental strategies in response to climate change. Therefore:

**Hypothesis 3**. Government ownership strengthens the positive relationship between climate change and energy utility firms adopting environmental management strategies.

Fig. 1 presents the theoretical framework of this study.
management strategies

## 3. Research methodology

### 3.1. Sample and data

In this study, we choose the energy utility firms listed in the Chinese stock markets as our focal point. On the one hand, within the context of global climate anomalies, the vast expanse of China faces a more diversified and frequent occurrence of climate-related and natural disasters, thereby exacerbating the supply pressures on energy utility firms. On the other hand, China's extensive population subjects energy utility firms to heightened scrutiny from multiple stakeholders. Stakeholders such as the government and the public increasingly demand stricter environmental responsibilities from these firms: environmental regulations and policies are continually strengthening, and public sentiment is widely concerned. Under climate change, Chinese energy utility firms tend to focus on economic benefits and proactively take measures to reduce adverse environmental impacts. Consequently, China's energy utility firms provide an ideal case for investigating the questions raised in this paper.

Our sample of on-list firms underwent the following process: (1) We retained energy utility firms operating in electricity, heat, gas, and water production and supply based on the industry codes provided by the CSMAR database. (2) We excluded ST (Special Treatment) firms within the observation period. (3) Data with severe financial or other indicator gaps were excluded. (4) We employed a two-tailed trimming of all control variables at the 1st and 99th quartiles to mitigate the impact of outliers. Subsequently, by matching these enterprises with the meteorological data via "city-year", we obtained 1037 observations spanning 706 energy utility firms from 2009 to 2021.

Climate-related data, such as temperature, wind speed, and rainfall, are sourced from the National Centers for Environmental Information (NCEI), a United States National Oceanic and Atmospheric Administration (NOAA) subsidiary. The primary data concerning publicly listed Chinese firms are obtained from the CSMAR database. The CSMAR database is currently China's largest and most comprehensive economic and financial research database and is widely used in the academic community (Hu et al., 2022). Data on corporate carbon emissions are derived from annual reports disclosed by firms in the form of social responsibility reports, sustainable development reports, and environmental reports, among others.

### 3.2. Variables

#### 3.2.1. Dependent variable

*Environmental management strategy (**Strategy**)*. Following the approach taken in many studies (Hojnik and Ruzzier, 2017), we regard the adoption of ISO 14001 standards as a signal that energy utility firms are actively embracing environmental management strategies. ISO 14001 is one of several environmental management system standards developed by the International Organization for Standardization (ISO), which provides a common language and a set of guidelines for environmental management by users (businesses and governments). ISO 14001 certification validates an organisation's ability to meet international standards in environmental management, ensuring the highest level of control over various emissions in processes, products, and activities while yielding positive economic returns (Amores-Salvadó et al., 2015). To measure environmental management system certification, we set up a dummy variable: a value of 1 is assigned to sample firms in a given year that have achieved ISO 14001 environmental management system certification, and 0 otherwise.

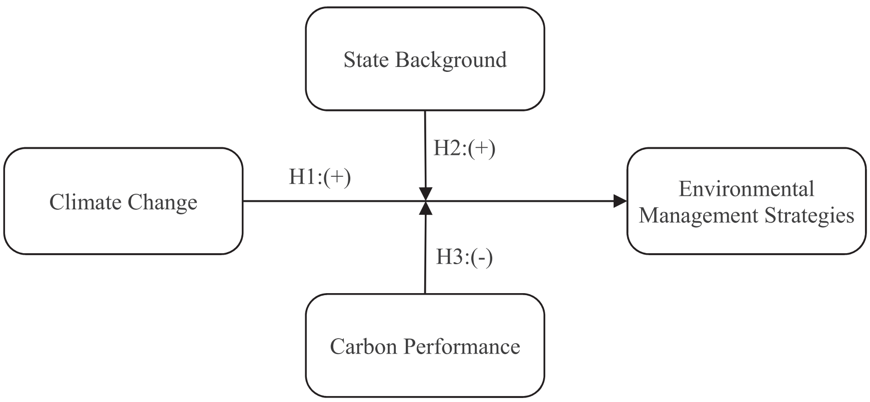


**Fig. 1.** The framework of the effect of climate change on environmental.

#### 3.2.2. Independent variable

*Climate change (**Climate**)*. We employ temperature fluctuations to identify climate effects, and for several reasons, temperature changes serve as a suitable proxy for climate shocks. First, high temperatures are exogenous to firms, meaning businesses have no control over when and where high temperatures occur (Tang et al., 2023). Second, for energy utility firms, the costs of changing production locations are prohibitive, making it practically impossible to relocate operations to avoid high temperatures. Third, the Earth is rapidly becoming hotter than ever before (Lovelock and Rapley, 2007), and the temperature has become a focal point in the majority of climate change literature (Chen and Yang, 2019; Heyes and Zhu, 2019; Tang et al., 2023). We obtained daily data from various meteorological observation stations across China, including the daily records and geographic coordinates of these stations, which we interpolated to create a nationwide daily average temperature grid using an inverse distance weighting method. Subsequently, we calculated each city's daily average temperature value by matching the administrative boundaries of China's prefecture-level cities with the temperature grid. Finally, we converted daily temperature data into annual averages, applying a natural logarithm transformation.

#### 3.2.3. Moderator variables

Carbon performance (***Carbon***). We measure this indicator using the ratio of carbon emissions to total revenue (Luo and Tang, 2014). Relative to absolute emissions, this intensity measurement enhances comparability across firms and different reporting periods.

State background (***SOEs***). Based on corporate ownership, if government institutions directly or indirectly control a company, it is classified as a state-owned enterprise (SOE) and assigned a value of 1; otherwise, it is designated as 0.

#### 3.2.4. Control variables

Profitability (***ROA***). Environmental management demands firms to pay substantial certification and maintenance costs. The stronger a company's profitability, the more likely it is to bear these expenses willingly. We employ Return on Assets (ROA) as a measure of profitability.

Capital intensity (***Intensity***). Firms may need funds to purchase equipment and technologies to enhance their production processes during environmental management. Consequently, firms with higher capital intensity are more inclined to adopt environmental management strategies. We gauge this metric using the ratio of capital to labour (Ni, 2019).

Firm size (***Size***). A company's size determines its overall strength and conduct. Larger firms have a competitive edge in the market, possess greater influence, and attract more stakeholder attention. The larger a company is, the more likely it is to initiate and sustain environmental management practices (Darnall, 2006; Mosgaard and Kristensen, 2020; Nishitani, 2009). We measure this metric using the natural logarithm of total assets.

Firm age (***Age***). The impact of company age on environmental management is a subject of debate. Optimistic views suggest that older firms may have advantages and experience in managing their environmental impact compared to younger ones (Yin et al., 2022). Pessimistic views argue that age leads to organisational inertia and a passive approach to challenges (Leyva-de la Hiz and Bolívar-Ramos, 2022). To represent company age, we calculate the difference between the observation year and the year of establishment, adding 1, and then take the logarithm.

Financial leverage (***Leverage***). High levels of debt may limit the adoption of environmental stewardship by firms. This indicator is expressed as a gearing ratio (total liabilities/total assets). It is measured by dividing total liabilities by total assets, cf. Tang et al. (2023).

Weather covariates (***Wind*** and ***Rain***). Following the common approach in existing literature (Cao et al., 2023; Chen and Yang, 2019), we include wind speed and rainfall as control variables. In line with the treatment of temperature variables, wind speed and rainfall data are further transformed from daily data to annual sums or averages. Precipitation is measured as the annual total, and wind speed as the annual average.

### 3.3. Model specification

Since the dependent variable ISO14001 is a dummy variable, we estimated the hypotheses using a binary logit model with robust standard errors. The formulas are as follows:

$$Logit(P) = \ln\left(\frac{P}{1-P}\right) = \alpha + \beta_1 Climate_{i,t} + \beta_2 Controls_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$Logit(P) = \ln\left(\frac{P}{1-P}\right) = \alpha + \beta_1 Climate_{i,t} \times Efficiency_{i,t} + \beta_2 Climate_{i,t}$$

$$+ \beta_3 Efficiency_{i,t} + \beta_4 Controls + \varepsilon_{it} \quad (2)$$

$$Logit(P) = \ln\left(\frac{P}{1-P}\right) = \alpha + \beta_1 Climate_{i,t} \times SOE_{i,t} + \beta_2 Climate_{i,t}$$

$$+ \beta_3 SOE_{i,t} + \beta_4 Controls_{i,t} + \varepsilon_{i,t} \quad (3)$$

Where $P$ denotes the probability that the energy utility adopts an environmental management strategy, the subscripts $i$ and $t$ denote

**Table 1**
Descriptive statistics and correlation analysis.

| | Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) | *Strategy* | 1.000 | | | | | | | | | | |
| (2) | *Climate* | 0.140*** | 1.000 | | | | | | | | | |
| (3) | *Carbon* | 0.016 | -0.030 | 1.000 | | | | | | | | |
| (4) | *SOEs* | -0.016 | 0.1103*** | -0.035 | 1.000 | | | | | | | |
| (5) | *ROA* | 0.052* | 0.122*** | 0.024 | -0.168*** | 1.000 | | | | | | |
| (6) | *Leverage* | -0.068** | -0.203*** | -0.060* | 0.244*** | -0.445*** | 1.000 | | | | | |
| (7) | *Age* | -0.089*** | 0.029 | -0.036 | 0.146*** | -0.098*** | 0.038 | 1.000 | | | | |
| (8) | *Size* | 0.032 | -0.042 | -0.052 | 0.243*** | -0.097*** | 0.389*** | 0.167*** | 1.000 | | | |
| (9) | *Intensity* | -0.022 | -0.070** | -0.013 | -0.021 | 0.033 | -0.138*** | 0.034 | 0.105*** | 1.000 | | |
| (10) | *Wind* | -0.019 | -0.228*** | 0.046 | -0.114*** | -0.067 | 0.044 | 0.046 | 0.042 | -0.024 | 1.000 | |
| (11) | *Rain* | 0.134*** | 0.734*** | -0.027 | 0.059* | 0.093*** | -0.207*** | 0.093*** | -0.083*** | -0.022 | -0.077** | 1.000 |
| | Obs. | 1037 | 1037 | 945 | 1037 | 1037 | 1037 | 1037 | 1037 | 1037 | 1037 | 1037 |
| | Mean | 0.088 | 2.655 | 0.497 | 0.839 | 0.039 | 0.546 | 2.939 | 23.091 | 0.839 | 2.538 | 44.025 |
| | SD. | 0.283 | 0.407 | 0.611 | 0.368 | 0.030 | 0.177 | 0.329 | 1.426 | 0.368 | 0.718 | 22.570 |
| | Min | 0.000 | 1.25 | 0.000 | 0.000 | 0.001 | 0.070 | 0.693 | 20.422 | 0.000 | 1.289 | 2.483 |
| | Max | 1.000 | 3.178 | 16.919 | 1.000 | 0.162 | 0.880 | 3.555 | 26.575 | 1.000 | 4.448 | 108.004 |

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$; In order to retain as much of the estimated sample as possible, we did not exclude other samples based on missing values in the Carbon data.

firm and year, respectively, α is the constant, $\beta_\gamma$ is the coefficient, the *Controls* are the control variables, and $\varepsilon_{it}$ is the error term. Model (1) - Model (3) were used to test hypotheses H1-H3, respectively.

## 4. Results

### 4.1. Correlation analysis and descriptive statistics

The descriptive statistics and correlation matrix are shown in Table 1. Notably , *Strategy* has a mean value of 0.088, which indicates that the low willingness of energy utilities to adopt environmental management strategy (only 8.8 %). The results indicate that there is no multicollinearity problem in this study. In addition, we also examined the variance inflation factor (VIF), and the results confirmed that there was no co-linearity problem as the mean VIF value was less than the critical value of 10.

### 4.2. Main results

Table 2 reports the results. Hypothesis 1 is supported. The results in Column 1 indicate that climate change (*Climate*) has a significant positive effect on adopting environmental management strategies (*Strategy*) by energy utilities (coefficient=1.325, $p< 0.1$), thus confirming Hypothesis 1.

**Hypothesis 2.** is supported. In Column 2, the interaction term *Climate*×*Carbon* is significantly negative (coefficient=-1.622, $p< 0.05$), indicating that carbon performance weakens the incentive for climate change to drive the adoption of environmental management strategies by energy utilities.

**Hypothesis 3.** is also supported. In Column 3, the *Climate*×*SOEs* interaction term is significantly positive (coefficient=1.678, $p< 0.1$), suggesting that state background reinforces the impetus for climate change to drive the adoption of environmental management strategies by energy utilities.

The results for control variables are largely consistent with previous related studies (see Column 1). A higher level of financial leverage (*Leverage*) in firms is associated with a lower probability of adopting environmental management strategies (coefficient =-1.253, $p< 0.1$). The probability of firms adopting environmental management strategies increases with their size (*Size*) (coefficient=0.220, $p< 0.01$) and decreases with their age (*Age*) (coefficient=-0.955, $p< 0.01$). While the coefficients for variables like *ROA* and *Intensity* have the expected signs, they are not statistically significant.

### 4.3. Robustness checks

We conducted a series of robustness checks to confirm the reliability of our main results. Subsections 4.3.1 to 4.3.6 are used to test Hypothesis 1, and subsection 4.3.7 is used to test Hypotheses 2 and 3.

**Table 2**
The impact of climate change on environmental management strategy.

| **Variables** | **(1)** | **(2)** | **(3)** |
|---|---|---|---|
| *Climate* | 1.325* | 2.405** | 0.358 |
| | (0.699) | (1.026) | (0.821) |
| *Climate*×*Carbon* | | -1.622** | |
| | | (0.725) | |
| *Climate*×*SOEs* | | | 1.678* |
| | | | (0.892) |
| *Efficiency* | | 4.670** | |
| | | (2.078) | |
| *SOEs* | | | -4.877* |
| | | | (2.499) |
| *ROA* | -0.093 | -0.449 | -1.223 |
| | (3.515) | (3.998) | (3.473) |
| *Leverage* | -1.253* | -1.436** | -1.164* |
| | (0.644) | (0.689) | (0.666) |
| *Age* | -0.955*** | -1.086*** | -0.941*** |
| | (0.273) | (0.272) | (0.282) |
| *Size* | 0.220*** | 0.182** | 0.249*** |
| | (0.080) | (0.089) | (0.081) |
| *Intensity* | -0.029 | -0.0179 | -0.025 |
| | (0.024) | (0.028) | (0.024) |
| *Weather Covariates* | Yes | Yes | Yes |
| *Constant* | -7.785*** | -9.529*** | -5.398** |
| | (2.516) | (3.484) | (2.486) |
| Observations | 1037 | 936 | 1037 |

Note: Robust Standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

#### 4.3.1. Temperature bins

Earlier, we estimated the average temperature's impact on firms' adoption of environmental management strategies. However, this approach overlooked the potential differential impacts of various temperature levels on firms. Therefore, we employ temperature bins to illustrate the effect of different temperature ranges (Tang et al., 2023). We divided the daily average temperature into nine temperature intervals, with a minimum of −12°C and a maximum of 30°C. As the reference group, we selected the 6°C to 12°C temperature range to prevent multicollinearity issues (Zhang et al., 2018). Column (1) of Table 3 reports the regression results of temperature bins, and Fig. 2 displays the estimated coefficients for various daily maximum temperature intervals. Using the 6°C to 12°C temperature interval as the baseline, both temperature decreases and increases influence the adoption of environmental management strategies by energy utilities. However, the impact of temperature is more significant in the intervals of 16°C to 18°C and 24°C to 30°C and above. It indicates that temperature increases and decreases drive energy utilities' adoption of environmental management strategies.

#### 4.3.2. Placebo test

Following the approach of Heyes and Zhu (2019), we conducted a placebo test using the method of reverse letter allocation. Specifically, we used reverse letter allocation to shuffle the temperatures of the Chinese cities where the sampled firms are located. For instance, Shenzhen, the first city listed in our sample in alphabetical order, was erroneously assigned temperatures from Jincheng City. As shown in column 2, the coefficient for climate change is not statistically significant, demonstrating that our original results are robust.

#### 4.3.3. Excluding holidays

The weather variables we constructed encompassed data for an entire year, including weather information for weekdays, weekends, and holidays. Notably, most industrial activities occur on weekdays, with machinery and equipment likely to have higher usage rates during weekdays than on weekends and holidays when they might be relatively idle. To address this, we removed weather data for weekends and holidays and used only the weather data for weekdays to reconstruct the weather variables. We then conducted a regression analysis using the newly constructed weather variables. As shown in column (3), the results remain robust.

#### 4.3.4. Addressing rare event bias

Due to the relatively low prevalence of energy utilities certified under ISO14001 (approximately 8.66 % of the total sample), using

**Table 3**
Results of the robustness tests.

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | Temperature bins | Placebo | Excluding holidays | Relogit | Cloglog | Excluding 2020 | Lag 1 period |
| <-12℃ | 0.012 | | | | | | |
| | (0.018) | | | | | | |
| -12℃~-6℃ | -0.027 | | | | | | |
| | (0.021) | | | | | | |
| -6℃~-0℃ | 0.030*** | | | | | | |
| | (0.010) | | | | | | |
| 0℃~6℃ | 0.005 | | | | | | |
| | (0.013) | | | | | | |
| 12℃~18℃ | 0.017* | | | | | | |
| | (0.010) | | | | | | |
| 18℃~24℃ | 0.011 | | | | | | |
| | (0.009) | | | | | | |
| 24℃~30℃ | 0.011* | | | | | | |
| | (0.007) | | | | | | |
| >30℃ | 0.039*** | | | | | | |
| | (0.013) | | | | | | |
| *Climate* | | 0.326 | 1.317* | 1.233* | 1.299** | 1.343* | 1.253* |
| | | (0.323) | (0.692) | (0.693) | (0.660) | (0.760) | (0.730) |
| *ROA* | -0.279 | -0.533 | -0.091 | 0.291 | -0.136 | -0.355 | 0.565 |
| | (3.660) | (3.439) | (3.511) | (3.484) | (3.244) | (3.701) | (3.974) |
| *Leverage* | -1.374** | -1.572** | -1.252* | -1.232* | -1.187** | -1.688** | -0.827 |
| | (0.645) | (0.675) | (0.645) | (0.639) | (0.592) | (0.711) | (0.742) |
| *Age* | -0.973*** | -0.896*** | -0.955*** | -0.943*** | -0.899*** | -0.922*** | -1.112*** |
| | (0.282) | (0.276) | (0.273) | (0.270) | (0.234) | (0.291) | (0.337) |
| *Size* | 0.163* | 0.264*** | 0.220*** | 0.214*** | 0.220*** | 0.301*** | 0.171** |
| | (0.095) | (0.092) | (0.080) | (0.079) | (0.076) | (0.087) | (0.086) |
| *Intensity* | -0.025 | -0.026 | -0.029 | -0.023 | -0.028 | -0.025 | -0.019 |
| | (0.025) | (0.026) | (0.024) | (0.023) | (0.022) | (0.024) | (0.024) |
| *Weather Covariates* | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| *Constant* | -6.672** | -6.464** | -7.763*** | -7.468*** | -7.956*** | -9.536*** | -6.207** |
| | (2.798) | (2.514) | (2.512) | (2.495) | (2.386) | (2.819) | (2.678) |
| Observations | 1037 | 980 | 1037 | 1037 | 1037 | 929 | 853 |

Note: Robust Standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

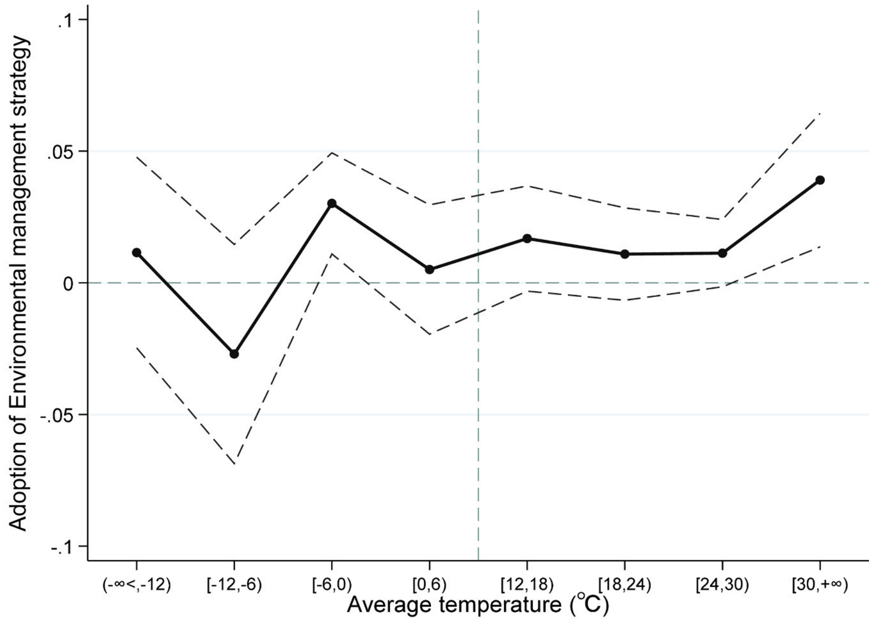


**Fig. 2.** Daily maximum temperatures and the adoption of environmental management strategy.

a direct logit regression model might lead to a "rare event bias". This study employs rare-event-based logit regression (Relogit model) and the complementary log-log model (Cloglog model) to mitigate this potential bias. As shown in Columns (4)-(5), the results remain robust.

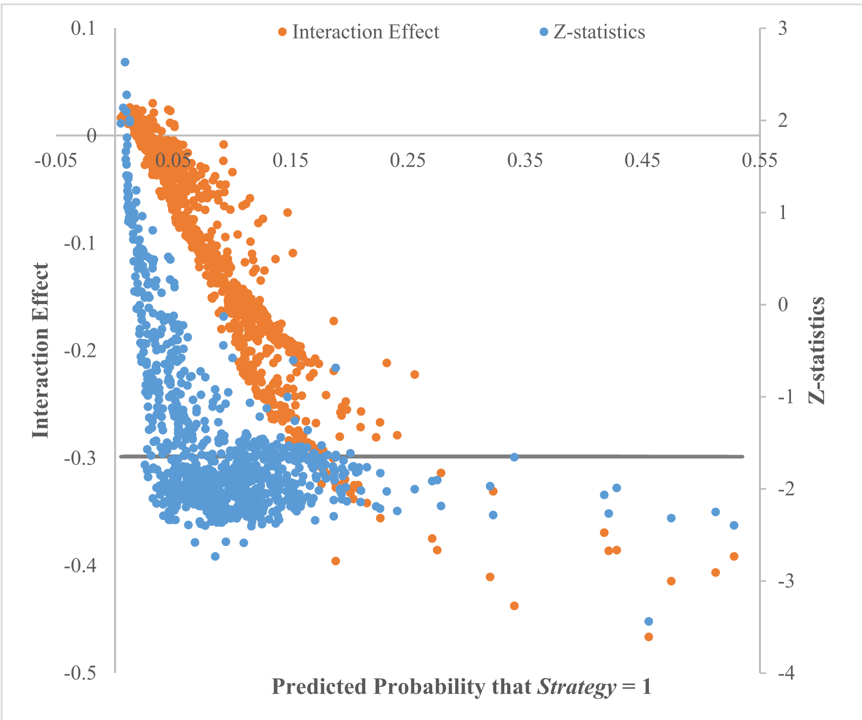


**Fig. 3.** Interaction effects of carbon performance and climate. Note: The marginal effects and associated z-statistics for the interactions between carbon performance and climate were computed using the Stata command "INTEFF" after applying a logit regression model.

#### 4.3.5. Controlling for the impact of the COVID-19 pandemic

The influence of the COVID-19 pandemic on energy consumption and global temperature increases cannot be disregarded. The lockdowns and restrictive measures implemented worldwide in response to the outbreak resulted in significant reductions in energy demand due to the suspension of various human activities, such as transportation, industrial production, and commercial activities, temporarily alleviating climate anomalies. Moreover, the economic uncertainty associated with the high prevalence of the pandemic led to more conservative corporate decision-making, potentially reducing the willingness to adopt environmental management strategies. In column (6), we retained observations from 2019 and earlier, and the results remain robust.

#### 4.3.6. Incorporating lagged independent variables

The adverse effects of climate change, such as high temperatures, on firm performance, may persist over several years (Chen and Yang, 2019). Simultaneously, climate change is a gradual process, and firms may require time to analyse and comprehend the potential impacts of climate change on their business operations and activities. Therefore, in column (7), we introduce a lag of one period to our independent variables, and the results remain robust.

#### 4.3.7. Utilising the INTEFF command

Considering the moderating effects of nonlinear main effects, using traditional tests of interaction term coefficient significance may introduce biases (Norton et al., 2004). In this study, we calculate the marginal effects of interaction terms in nonlinear models using the STATA "INTEFF" command, following the method of Norton et al. (2004). The dashed lines in the figures represent the 10 % significance level Z-values. As observed in Fig. 3, carbon performance predominantly exhibits a negative substantive moderating effect on the relationship between climate change and the adoption of environmental management strategies, with over 60 % of the interaction effects significant at the 10 % level. Similarly, Fig. 4 illustrates that state ownership primarily exhibits a positive substantive moderating effect on the relationship between climate change and the adoption of environmental management strategies, with over 60 % of the interaction effects significant at the 10 % level. In summary, these findings partially support Hypotheses 2 and 3.

### 4.4. Additional tests

#### 4.4.1. Heterogeneity in costs and revenues

Suppose climate change induces additional operational burdens on energy utility firms, leading to the adoption of environmental management strategies. In that case, businesses constrained by higher operating costs may exhibit greater sensitivity to extreme heat. We grouped enterprises based on their cost characteristics using Eq. (1). We measured the operational costs of energy utility firms by the ratio of operating expenses to total assets. Enterprises with operational costs above the median were designated as high operational

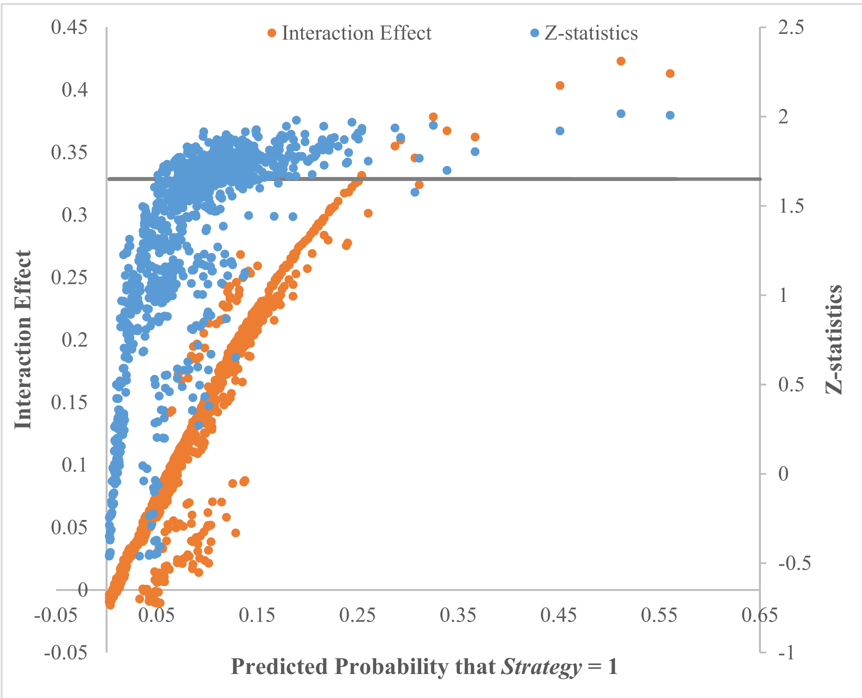


**Fig. 4.** Interaction effects of SOEs and climate. Note: The marginal effects and associated z-statistics for the interactions between SOEs and climate were computed using the Stata command "INTEFF" after applying a logit regression model.

cost firms, while those below the median were categorised as low operational cost firms. The results presented in Table 4 indicate that, for energy firms with higher operational costs, the adoption of environmental management strategies is more likely to be influenced by high temperatures.

Furthermore, we also examined whether income plays a significant role in the causal relationship between climate change and environmental management strategies. We grouped enterprises based on their income characteristics using Eq. (1). We assessed the income level of energy utility firms by the ratio of operating revenue to total assets. Enterprises with income above the median were classified as high-income firms, while those below the median were classified as low-income firms. The results in Table 4, columns (1) and (2), demonstrate that environmental management strategies are less sensitive to climate change for firms with higher income levels.

The above findings suggest climate change can alter energy utility firms' operating costs and income levels, subsequently influencing their environmental management strategies.

#### 4.4.2. Heterogeneity in firm social responsibility and media attention

Suppose the environmental management activities of energy utility firms under climate change are seen as a response to public social responsibility expectations. In that case, enterprises with high media attention and weaker social responsibility performance should be more closely scrutinised by the public and more sensitive to the impact of climate change. We conducted grouped estimations using Eq. (1). Following the approach by Zhang et al. (2014), we used the amount of corporate donations as a measure of corporate social responsibility. Firms making donations were categorised as high social responsibility enterprises, while those not were classified as low social responsibility enterprises. In line with Huang et al. (2021), we obtained positive news coverage data for listed firms in China from the China Financial News Database (CFND). We used it as a measure of media attention. Firms with media attention levels greater than the median were designated high-reputation firms, while those below the median were considered low-reputation firms. The results in Table 5, columns 1–4, demonstrate that energy utility firms with lower social responsibility performance or greater media attention are more sensitive to climate change.

## 5. Discussions

Firstly, we have theoretically and empirically confirmed that a key feature of climate change - rising temperatures - drives energy utility firms to adopt environmental management strategies. Our research complements prior studies on the relationship between climate change and corporate behaviour. Previous research suggested that firms proactively respond to climate change in ways such as improving productivity or tax avoidance (Chen and Yang, 2019; Tang et al., 2023). We extend this work by demonstrating that climate change can incentivise firms to adopt environmental management strategies. Going further, our analysis reveals that the influence of climate change on energy utilities operation through channels such as costs and media scrutiny. Previous studies have affirmed the role of climate change on operating costs and stakeholder concerns (Barrot and Sauvagnat, 2016; Huynh and Xia, 2021; Safiullah et al., 2022; Testa et al., 2018). We validate this view and find that firms with high costs or high media concerns are more sensitive to climate change.

Secondly, our study reveals that carbon performance weakens the impetus of climate change on energy utility firms to adopt environmental management strategies. Previous research often linked high carbon performance to positive environmental management, as higher carbon performance enhances environmental capabilities through energy efficiency and financial performance improvement (Busch and Lewandowski, 2018; Siddique et al., 2021; Trinks et al., 2020). In our study, firms with high carbon performance may perceive that they have already made significant efforts and progress in environmental management, reducing their

**Table 4**
Effects of climate change on environmental management strategy in costs and revenues.

| Variables | High cost | Low cost | High income | Low income |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| *Climate* | 2.276* | 0.132 | -0.083 | 2.673** |
| | (1.192) | (0.781) | (0.786) | (1.267) |
| *ROA* | 1.115 | -1.770 | -2.852 | 3.809 |
| | (4.612) | (7.086) | (7.539) | (4.344) |
| *Leverage* | -1.673* | -0.390 | -0.180 | -1.720* |
| | (0.951) | (0.857) | (0.888) | (0.945) |
| *Age* | -0.057 | -1.578*** | -1.618*** | -0.081 |
| | (0.532) | (0.410) | (0.426) | (0.528) |
| *Size* | 0.143 | 0.319** | 0.336** | 0.114 |
| | (0.115) | (0.139) | (0.143) | (0.111) |
| *Intensity* | -0.089** | -0.079 | -0.143 | -0.096*** |
| | (0.035) | (0.181) | (0.175) | (0.037) |
| *Weather Covariates* | Yes | Yes | Yes | Yes |
| Constant | -10.546*** | -5.470 | -5.332 | -10.541*** |
| | (3.628) | (3.716) | (3.696) | (3.908) |
| Observations | 518 | 519 | 519 | 518 |

Note: Robust Standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

**Table 5**
Heterogeneity in firm social responsibility and reputation.

| Variables | High attention | Low attention | High CSR | Low CSR |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| *Climate* | 2.144** | 0.899 | -0.228 | 1.726* |
| | (0.992) | (0.803) | (1.035) | (0.893) |
| *ROA* | 3.664 | -0.295 | -1.506 | 2.315 |
| | (5.808) | (4.555) | (9.774) | (3.473) |
| *Leverage* | 0.112 | -1.950** | -1.502 | -1.282* |
| | (0.959) | (0.852) | (1.599) | (0.736) |
| *Age* | -1.028*** | -1.047*** | -2.200*** | -0.809** |
| | (0.346) | (0.402) | (0.753) | (0.325) |
| *Size* | 0.206 | 0.440*** | 0.291* | 0.200** |
| | (0.134) | (0.136) | (0.162) | (0.102) |
| *Intensity* | -0.000 | -0.043 | -0.269** | 0.005 |
| | (0.031) | (0.032) | (0.128) | (0.022) |
| Weather Covariates | Yes | Yes | Yes | Yes |
| Constant | -10.985*** | -10.383*** | -1.832 | -8.598*** |
| | (4.206) | (3.150) | (4.226) | (3.195) |
| Observations | 521 | 503 | 218 | 819 |

Note: Robust Standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

willingness to further adopt such strategies in the context of climate change. This aspect of our research provides a novel perspective on why some firms might react passively to climate change.

Furthermore, we incorporate government ownership into the analysis framework of climate change's impact on energy utility firms' environmental behaviour. In the face of rising temperatures, we find that state-owned energy utility firms are more motivated to adopt environmental management strategies than non-SOEs. The role of government ownership in influencing environmental performance in energy utility firms remains a subject of intense debate (Meyer and Pac, 2013). Our research supports the viewpoint that advocates for extending economic regulation to the public sector and suggests that privatisation may not be an effective policy tool for addressing environmental performance deficiencies in public utility firms (Beecher and Kalmbach, 2013; Scott et al., 2019).

Lastly, the results regarding control variables warrant discussion. Higher corporate leverage significantly reduces a firm's willingness to adopt environmental management practices, reflecting the impact of financial constraints (Liu et al., 2021; Tian and Lin, 2019). Older firms are less likely to engage in environmental management, aligning with previous arguments that ageing firms may exhibit organisational inertia (Leyva-de la Hiz and Bolívar-Ramos, 2022). Thus, the advantages and experience of older energy utility firms in environmental management merit further discussion. Firm size partly represents the firm's financial strength and media attention. Larger firms are more likely to implement environmental management practices, consistent with previous literature (Mosgaard and Kristensen, 2020; Nishitani, 2009). Additionally, differences in sample selection, variable construction, and model choice could explain the variations in significance levels observed in the remaining control variables in our study compared to prior literature.

## 6. Conclusions, policy recommendations and limitations

In this study, we employ annual data at the firm level for 2008–2021 in China, coupled with detailed daily weather datasets, to assess the impact of temperature variations on adopting environmental management strategies by Chinese energy utility firms. Several key findings emerge from this study. Firstly, as temperatures rise, the probability of energy utility firms adopting environmental management strategies increases. Secondly, the state-owned background of firms reinforces this effect. Lastly, the level of corporate carbon performance weakens this influence.

Our research holds policy implications on two fronts. Firstly, the increasing public and media scrutiny has become a driving force behind energy utility firms adopting environmental management strategies. For governments, it is crucial to strengthen public awareness and engagement in climate change and environmental management. It can be achieved through public education and awareness campaigns. Simultaneously, promoting higher levels of environmental disclosure by firms is essential. It encourages firms to fulfil their environmental management obligations responsibly and facilitates public oversight.

Secondly, corporate carbon performance and government ownership lead energy utility firms to exhibit differing attitudes towards climate change, resulting in varying environmental management decisions. Thus, governments need to intensify supervision over non-state-owned and lower-performing carbon energy utility firms and provide support, such as increased research and development funding and technological assistance, to encourage them to play a more substantial role in environmental protection.

This study has several limitations, which provide directions for future research. First, we use ISO 14001 criteria to gauge a firm's environmental management strategies in response to climate change. Future research could delve further into a firm's strategic behaviours, such as ESG (Environmental, Social, and Governance) practices and green innovations. Second, China's unique political and cultural context may restrict these findings' generalizability to other countries or regions. Future studies may extend the research contexts in other countries, particularly developing economies.

## CRediT authorship contribution statement

**Tianle Yang:** Software, Resources, Project administration. **Anna Min DU:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Conceptualization. **Zhongyuan Li:** Software, Resources, Methodology, Formal analysis. **Mengzhe Xue:** Methodology, Formal analysis, Data curation. **Qunyang Du:** Writing – original draft, Funding acquisition, Formal analysis, Conceptualization.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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