Energy Economics 95 (2021) 105136

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneeco

What are the shocks of climate change on clean energy investment: A diversified exploration

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ARTICLE INFO

Article history:
Received 25 October 2020
Received in revised form 1 January 2021
Accepted 15 January 2021
Available online 26 January 2021

Keywords:
Climate change
Extreme weather events
Clean energy investment
Heterogeneity

JEL classifications:
Q20
Q54

ABSTRACT

Climate change may affect energy consumption and thus bring shocks to clean energy investment. By employing instrumental variable quantile regression model, this research investigates the effects of climate change on clean energy investment according to global panel data spanning a long period. In addition to the sample of all countries, we also carry out investigations of sub-samples for OECD and non-OECD countries to analyze whether there exists heterogeneity in development levels. Overall, we provide a diversified exploration on how climate change shocks impact clean energy investment. More specifically, we find that effects of climate change on clean energy investment vary significantly in countries with different levels of clean energy investment; i.e., climate change is likely to promote clean energy investment in countries whose clean investments are greater, and there exists significant heterogeneity in the subsamples. From these results, we offer policy implications such as carrying out differentiated clean energy plans based on the specific environment, implementing policies on clean energy, and copying the practices in some OECD countries that have high levels of clean energy investment.

1. Introduction

Depletable fossil fuels are the main source of energy supply, but can lead to a series of climate change problems. Investment in clean energy can meet energy demand and mitigate climate problems (Wüstenhagen and Menichetti, 2012), and thus analysis on the relationship between climate change and clean energy investment is of great significance. Climate change aggravates global warming and brings about potential risks for both human society and natural systems (Wei et al., 2015; Polzin et al., 2015), resulting in a serious impact on environmental degradation (Warner et al., 2010), which is a major issue within global environmental policy (Baležentis et al., 2016; Wang et al., 2020a). In addition to the climate change induced disasters, some accidental hazards, such as natural disasters (Chang and Zhang, 2020; Chen and Chang, 2020) and pandemics, may affect energy market volatility (Salisu and Adediran, 2020; Salisu and Sikiru, 2020; Apergis and Apergis, 2020; Devpura and Narayan, 2020; Iyke, 2020a; Narayan, 2020b), stock market (Prabheesh et al., 2020; Sharma, 2020; Yan and Qian, 2020; KP, 2020; Appiah-Otoo, 2020; Narayan, 2020a; Narayan, 2020b; Narayan et al., 2020), global trade network (Vidya and Prabheesh, 2020), and further influence the functioning of energy markets (Narayan, 2020b; Liu et al., 2020; Fu and Shen, 2020; He et al. (2020a), leading to recession and unemployment (Qin et al., 2020a; Polemis and Soursou, 2020; He et al., 2020b; Yu et al., 2020). Then the unprecedented uncertainty may emerge in the supply market and demand curve should have the tendency to shift (Haroon and Rizvi, 2020; Phan and Narayan, 2020; Mishra et al., 2020; Iyke, 2020b), which may produce great impacts on the energy consumption and environmental quality (Hao and Wu, 2020; Ming et al., 2020; Qin et al., 2020b). Faced with increasingly severe environmental problems, countries around the world are setting up climate targets that require emission reductions. Governments tend to relieve the environmental pollution through energy deployment (Li and Feng, 2020).

Since clean energy has the advantages of lower energy input requirements and fewer emissions, it is more effective at achieving the critical targets of better sustainability, and a high share of clean energy is needed in order to decrease greenhouse emissions in a country portfolio (Dincer and Acar, 2015; Busu, 2019). With their development, the integration of clean energy technologies is currently playing an important role in climate change mitigation (Perera et al., 2017). Government policies, such as putting a price on carbon dioxide emissions, encouraging investment in new clean energy technology, are implemented to level the economic playing field between clean and dirty energy (Sivaram and Norris, 2016). The scale of the clean energy industry has also been expanding and the utilization of clean energy has turned more critical in response to serious environmental problems. Thus, more and more investors are beginning to target clean energy firms in

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https://doi.org/10.1016/j.eneco.2021.105136
0140-9883/

their portfolio (Liu and Zeng, 2017). Investments in solar, wind, and geothermal energy are of particular concern, because the development of solar technologies forms a key solution to satisfy the increasing demand for energy (Kabir et al., 2018), wind energy is one of the most important sustainable energy resources, and present technology is making it possible to encourage geothermal energy investment and development (Ackermann and Söder, 2000; Barbier, 2002). Therefore, this paper focuses on impacts from climate change on investments in the solar, wind, and geothermal industries.

Investment in clean energy over the last few decades has significantly increased around the world. Fig. 1 illustrates the installed capacities of solar, wind, and geothermal energy globally, from which we see that clean energy investment has risen dramatically from 1995 to 2018. From 2008 onward, clean energy investment became more urgent, most likely due to climate change, which has induced various degrees of environmental damage. Global Trends point out that the most cost-effective solution to avoid climate change scenarios is to utilize existing solar, wind, and geothermal energy (Energy and Efficiency, 2008). Among the datapoints, the installed capacities of solar and wind energy have reached nearly 500 gigawatts in 2018, whereas the development of geothermal energy is lower than that of solar and wind, with it at just 15 gigawatts in 2018.

Existing research has shown that climate change does affect the usage and investment of clean energy, but there is scant literature stating the mechanism of how climate change affects clean energy investment comprehensively. As GHG emissions, extreme temperatures, and extreme weather events are the main forms of climate change (Hansen et al., 2012), we focus on the specific mechanism of these three factors affecting clean energy investment. Fig. 2 illustrates the mechanism of climate change on clean energy investment.

When talking about the influences of greenhouse gases on clean energy investment, greenhouse gases are the cause of global warming, and with the increase of greenhouse gas emissions, the awareness of environmental protection has increased internationally, thus leading to a rise in clean energy consumption. Sims (2004) analyzes the impacts of carbon dioxide emissions on the global clean energy industry and finds that carbon dioxide emissions affect the supplies of clean energy sources. Sadorsky (2009) studies the relationship between clean energy consumption and carbon dioxide emissions in the Group of 7 countries, showing results that carbon dioxide emissions contribute positively to the consumption of clean energy. Menyah and Wolde-Rufael (2010) explore the causal relationship between carbon dioxide emissions and clean energy consumption using a modified Grange causality test over the period 1960 to 2007 in the U.S. Their empirical results illustrate a unidirectional causality from carbon dioxide emissions to clean energy consumption. Aguirre and Ibikunle (2014) come to a similar conclusion, by employing country-level samples to reveal the influencing factors of clean energy through FEVD and to find that carbon dioxide emission levels are significant factors of clean energy participation. Usman et al. (2020) examine the asymmetric effects of clean energy consumption on greenhouse gas emissions, and the results confirm that carbon emissions respond positively to clean variables. Thus, clean energy has potential for improving environmental quality.

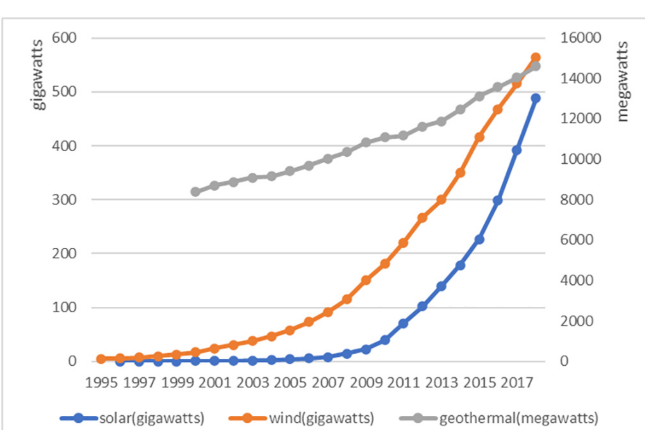

Fig. 1. Worldwide renewable capacity investment from 1995 to 2018.

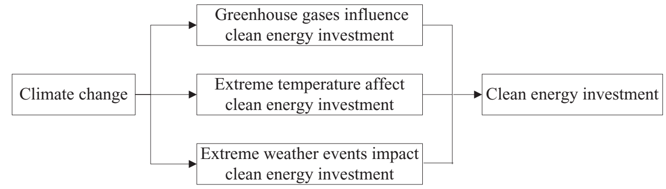

Fig. 2. The influence mechanism of climate change on clean energy investment.

In terms of the influences of extreme temperature on clean energy investment, extreme temperature may endanger energy production and consumption, blackouts due to extreme temperatures have increased by several times between 1980 and 2012 in the U.S. (Kenward and Raja, 2014). A heat wave may also lead to greater energy demand due to air conditioning; at the same time, it may put the electricity generation system under stress, which could finally lead to blackouts. Moreover, extreme temperatures damage energy facilities and affect energy production, resulting in supply cuts of different magnitudes that impact other infrastructures (Pryor et al., 2014). The existing literatures show that nearly 40% of the nuclear power plants in Europe have been damaged due to extreme temperatures (Añel et al., 2017).

As it relates to the influences of extreme weather events on clean energy investment, extreme weather events affect both the demand of energy and the resilience of the energy supply system, further influencing clean energy investment. As extreme weather events have significant impacts on critical power infrastructures, there is an urgent need to decrease the effects of climate change, which is a key driver for developing more sustainable energy systems (Panteli and Mancarella, 2015). Pryor et al. (2006) apply a downscaling technique to generate probability distributions of wind speed and simulate its profound societal impacts. Their conclude that when faced with extreme weather events, wind energy will continue to be a stable resource for electricity generation in the near future in northern Europe. Perera et al. (2020) develop a stochastic-robust optimization method to examine the impact of extreme weather events on clean energy's potential demand and note that extreme weather events can lead to a statistically significant performance gap between power demand and supply, leading to an urgent need for clean energy investment.

Based on the current situation of climate change and clean energy investment, several questions arise pertaining to the relationship between climate change and clean energy investment. Are there differences in the effects of climate change on clean energy investment between different kinds of clean energy? Do the effects vary under different forms of climate change? As clean energy investment reflects the development of clean energy in a country, does the previous investment level influence new investment in clean energy - that is, do the effects of climate change on clean investment differ significantly between countries with different levels of clean investment? Do the effects of climate change on clean investment exhibit heterogeneity between different economic development regions? In order to investigate the questions above, we employ the instrumental variable quantile regression model with fixed effects. The advantage of this model is that it enables us to analyze various conditional quantiles of the dependent variable and can be used to check the changing effects of an independent variable at different levels of the dependent variable (Zheng et al., 2019), thus revealing heterogeneity in the analysis of clean energy investment and answering the question on whether the effects of climate change on clean investment differ significantly between countries with different levels of clean investment. Moreover, the individual specific effect can be controlled, which may offer a more flexible approach for a quantile regression framework. Therefore, we use installed capacities of solar, wind, and geothermal energies to proxy for clean energy investment, utilize greenhouse gases, extreme temperatures, and extreme weather events to measure climate change, and provide a diversified exploration on how climate change influences clean energy investment. The results show that the effects of climate change on clean energy investment vary significantly in countries with different levels of clean energy investment, and that there exists significant heterogeneity in the subsamples.

Since high-income countries care more about environmental problems, they pay greater attention to innovation and clean energy investment (Chang et al., 2018a; Wen et al., 2020; Li et al., 2020). Specifically, OECD countries have been reducing pollutant discharge by promoting clean energy use and investment (Paramati et al., 2017). Thus, our analysis takes into consideration the heterogeneity of climate change on clean energy investment between OECD and non-OECD countries. As extreme temperatures and weather events, including floods and droughts, are important aspects of climate change, how these phenomena affect clean energy investment is a topic worthy of discussion. Our research overall contributes to the literature in several aspects as noted below. First, we investigate the shocks of climate change on clean energy investment from three aspects: solar, wind, and geothermal energies. Second, we utilize the quantile regression model to examine whether countries with varying levels of clean energy investment respond to climate change differently, making it the first study to examine the varying effect of climate change on clean energy investment along the entire length of clean energy investment distribution. Finally, we take heterogeneity into consideration and analyze the differences in the effects of climate change on clean energy investment between OECD and non-OECD countries.

The remainder of the paper runs as follows. Section 2 summarizes the relevant literature. Section 3 presents the data and method. Section 4 reveals the empirical analysis and robustness tests. Section 5 concludes and offers policy implications.

2. Literature review

Climate change is a multifaceted hazard that has various aspects and unknown outcomes, and science has clearly shown that the probability of floods, droughts, and global warming is likely to continue to grow (Stern, 2008). Greenhouse gas (GHG) emissions consist of carbon dioxide, methane, nitrous oxide, etc., while extreme temperatures and extreme weather events, including floods and droughts, are the main forms of climate change (Dodman, 2009; Hansen et al., 2012). These three factors of climate change bring have great influences on both the environment and human life. Global warming caused by GHG emissions has been a major concern around the world, as extreme temperatures could cause a nearly 16% loss in the generation capacity of U.S power plants, and extreme weather events are very significant problems for all activities and are transversal throughout natural systems (Añel et al., 2017). Therefore, the main objective of this paper is to examine how GHG emissions, extreme temperatures, and extreme weather events influence clean energy investment.

Clean energy denotes energy from the natural and persistent flow of energy happening in the environment, which includes solar energy, wind energy, geothermal energy, water energy, bioenergy energy, hydrogen and fuel cells, as well as nuclear energy.[2] As clean energy consumption is considered as an effective way to deal with climate change (Gan et al., 2007; Foxon and Pearson, 2007; Jefferson, 2008), many scholars have carried out research on their nexus. The research mainly focuses on the following aspects: the economic effects of clean energy, the environmental effects of clean energy, and how climate change influences clean energy consumption.

On the economic effects of clean energy, some scholars have studied the causal relationship between clean energy and economic development. Yang (2000) tests the two-way casualty between clean energy and economic development for the period 1954–1997 in Taiwan, and empirical results confirm the existence of bidirectional causality between the two. Apergis and Payne (2012) examine the relationship between clean energy consumption and economic growth using panel data of 80 countries over the period 1990–2007. The results of panel error correction model confirm that there exists bidirectional causality between clean energy consumption and economic growth in both the short and long-run. There are researches focusing on whether clean energy can promote economic development. Chien and Hu (2008) investigate the effects of clean energy on GDP using global country data and find that clean energy increases GDP significantly. Mahmoodi and Mahmoodi (2011) examine the relationship between clean energy consumption and economic growth using panel data of 7 Asian countries. The results also prove that renewable energy consumption significantly promotes economic growth in most Asian countries. Many scholars analyze the relationship between clean energy and economic development using different samples and arrive at a similar conclusion (Apergis and Payne, 2011; Chien and Hu, 2008; Li et al., 2011).

On the environmental effects of clean energy, the main point is that clean energy plays a vital role in sustainable development and can mitigate greenhouse gas emissions significantly (Zeb et al., 2014; Fuss et al., 2012). Bölük and Mert (2014) analyze the relationship between energy consumption and greenhouse gas emissions using panel data over the period of 1990–2008 in 16 EU countries, the empirical results show that carbon emissions of clean energy are about half that of fossil energy through panel data analysis of European Union countries. Gill et al. (2018) examine the effects of clean energy on greenhouse gas emissions employing times series data from1970 to 2011 in Malaysia and find that clean energy production exudes a significantly negative effect on CO_2 emissions.

In the analysis of how climate change influences clean energy investment, the main conclusion is that climate change and climate-induced environmental pollution are conductive to such investment (Liu and Zeng, 2017). As clean energy technologies are assumed to play an important role in mitigating the shocks of climate change (Fuss et al., 2012), a large portion of foreign assistance is directed to clean energy facilities (Buntaine and Pizer, 2015). The share of clean energy within global energy has increased through enhanced international cooperation that helps facilitate access to clean energy technology and improve clean energy investment (Das and Bandyopadhyay, 2016). Haines et al. (2007) illustrate that climate change driven by energy use has threatened human health, and that clean energy investment should be promoted so as to mitigate climate disruption. Asumadu-Sarkodie and Owusu (2016) investigate the relationship between carbon dioxide emissions and clean energy use via the vector error correction model. Their results show unidirectional causality running from CO_2 emissions to clean energy use, and that the usage of clean energy technologies can play an important role in mitigating climate change. Consistent with Asumadu-Sarkodie and Owusu (2016), Nyambuu and Semmler (2020) propose a dynamic growth model using both clean energy and traditional energy, with solutions suggesting that clean energy is effective in dealing with climate change.

From the literature above we see that it focuses on the relationship between clean energy consumption and economic development, clean energy usage, and environmental pollution, with scant research targeting how climate change influences clean energy investment. Moreover, there is no study in the literature on whether the impact of climate change on clean energy investment is influenced by the level of clean energy development. This paper thus fills this gap on how climate change influences clean energy investment and whether the effect

[2] https://www.energy.gov/science-innovation/clean-energy.

presents heterogeneity in countries with different clean energy investment levels.

3. Data description and method

3.1. Data and variables

This present study investigates the effect of climate change on clean energy investment with panel data ranging from 1996 to 2018. We employ panel data of country level for different kinds of clean energy. In the analysis of solar investment, there are 44 countries, including 26 OECD countries and 18 non-OECD countries; in the analysis of wind energy investment, there are 41 countries including 25 OECD countries and 16 non-OECD countries; and in the analysis of geothermal energy investment, there are 19 countries, including 11 OECD countries and 8 non-OECD countries. The list countries included in our analysis is presented in Appendix Table A1.

The dependent variables are the installed capacities of solar (*Solar*), wind (*Wind*), and geothermal energy (*Geothermal*). Capacity can represent the most accurate proxy for the deployment of a technology (Popp et al., 2011). Thus, referring to Polzin et al. (2015), we use capacity indicators to measure clean energy investment.

The independent variables consist of a series of climate change dimensions. Referring to Burnell (2012), we utilize greenhouse gas emissions, extreme temperatures,[3] and extreme weather events, including droughts and floods, to measure the different aspects of climate change, respectively. Total greenhouse gas emissions (*GHG*) measured in million tons of 'carbon dioxide-equivalents' are used to reflect the global warming effect. As carbon dioxide is the main component of greenhouse gases, we use carbon dioxide emissions (*CO2*) to conduct the robustness test. The numbers of extreme temperatures (*Extreme_N*), droughts (*Drought_N*), and floods (*Flood_N*), and the total loss caused by extreme temperatures (*Extreme_L*), droughts (*Drought_L*), and floods (*Flood_L*) are used to control for the influence of extreme events' frequency and to distinguish large events from small ones (Ward and Shively, 2017).

In order to ensure the efficiency and robustness of the estimation results, some additional control variables are taken into the analysis. Real gross domestic product (constant 2010 US$) (*GDP*) is employed to capture economic development. Since population may influence the efficiency of energy consumption (Morikawa, 2012), we utilize total population (*Popu*) to reflect the population factors of a country. Sadorsky (2011) believes that increasing trade affects energy consumption in both the short run and long run, and thus the ratio of trade to GDP is used to represent the trade level in a country. The structure of energy consumption greatly affects a series of environmental problems, such as environmental pollution, greenhouse effect, and so on, which further influence the decision-making for clean energy investment. Hence, we account for the proportion of clean energy consumption to total final energy consumption (*Energy*) to reflect the structure of energy consumption (Bilgen, 2014). As reliable public support can positively influence investors, following Polzin et al. (2015), we also take national public policy on clean energy (*Policy*) into our analysis. Generally, the cost of clean energy is higher than that of traditional energy, which may impede clean energy investment (Labordena et al., 2017). As a substitute for clean energy, natural resource abundance is conducive to improving clean energy production in a country. Therefore, we employ the ratio of natural resource rents to GDP (*Rent*) to reflect the cost of natural resources (Ahmadov and van der Borg, 2019). In the EI Nino years, the frequency and intensity of extreme weather events will increase, thus, we utilize dummy variable (*EI Nino*) to represent whether there exist EI Nino. Table 1 shows the data definition, sources, and description statistics of variables.

[3] Extreme temperatures include cold wave, heat wave and severe winter conditions, such as snow and freeze.

3.2. Model

The quantile regression is originally proposed by Koenker and Bassett (1978), then fixed effects are introduced into the quantile regression (Koenker, 2004). Since the fixed effects quantile regression model takes the heterogeneity of parameters into account and amends the deviation caused by the traditional fixed effect model, the method has been widely used both in cross-section data and panel data (Koenker, 2004). The instrumental variable quantile regression method appears in Chernozhukov and Hansen (2008) and further optimized by mixing fixed effects into the regression (Harding and Lamarche, 2009). There are many advantages for this model. One is that it can help test the influence of independent variables on dependent variables at different quantiles of conditional distribution of dependent variables. Moreover, the factors which cannot be observed, but may affect the dependent variables and relate to the explanatory variables are also taken into consideration (Chang et al., 2018b).

The fixed effects instrumental variable quantile model is thus utilized in our analysis. The basic panel data model is:

$$y_{it} = \alpha_i + X'_{it}\beta + G'_{it}\gamma + \varepsilon_{it} \tag{1}$$

$$G_{it} = f(X_{it}, Z_{it}, e_{it}) \tag{2}$$

$$\alpha_i = g(X_{i1}, \ldots, X_{iT}, G_{i1}, \ldots, G_{iT}, v_i) \tag{3}$$

where i denotes country; t represents time period; i ranges from 1 to N; t ranges from 1 to T; y_{it} is the dependent variable that represents clean energy investment, including installed capacities of solar energy (*Solar*), wind energy (*Wind*), and geothermal energy (*Geothermal*); X_{it} means the vector of exogenous variables, which includes climate change indicators for greenhouse gases (*GHG*), extreme temperature (*Extreme*), extreme weather events as *Drought* and *Flood*, and control variables like clean energy policy (*Policy*), total population (*Popu*), natural resource rents (*Rent*), economic development (*GDP*), merchandise trade (*Trade*), industrial structure (*Indus*), and clean energy consumption (*Energy*); *Git* is a vector of endogenous variables that are related to exogenous variables X_{it} and instruments Z_{it}; $\alpha_i$is the cross-specific effect; ε_{it} and e_{it} are the error terms; and v_i is independent of ε_{it} and e_{it}.

When taking the varying influence of climate change on clean energy investment into consideration, the panel quantile regression model can be re-written as Eqs. (4) and (5).

$$y_{it} = W'_{it}\alpha(\varepsilon_{it}) + X'_{it}\beta(\varepsilon_{it}) + G'_{it}\gamma(\varepsilon_{it}) \tag{4}$$

$$Q^S_y(\tau|W, X, G) = W'_{it}\alpha(\tau) + X'_{it}\beta(\tau) + G'_{it}\gamma(\tau) \tag{5}$$

where
W_{it} denotes the indicator variable that presents the individual specific effect; Q^S_y is structural quantile function; $\tau$is the τ^{th} quantile of Q^S_y; and ε_{it} is the error term that follows a uniform distribution. According to Chernozhukov and Hansen (2008), this model can be estimated as:

$$\begin{aligned}&\left\{\hat{\alpha}(\tau,\gamma), \hat{\beta}(\tau,\gamma), \hat{\gamma}(\tau,\gamma)\right\}\\&= \arg\min_{\alpha,\beta,\gamma} \sum_{t=1}^{T}\sum_{i=1}^{N} \rho_\tau\left(yit - W'_{it}\alpha - X'_{it}\beta - G'_{it}\gamma - \hat{Z}'_{it}\eta\right)\end{aligned} \tag{6}$$

where $\rho_\tau(\cdot)$ presents the loss function of quantile regression; $\widehat{Z}$ is the least squares forecasts of W, X, G, and Z; and Eq. (6) can be minimized for α, β, and η and is a function of τ and γ. The parameter can be estimated on the endogenous variable, which minimizes the objective function shown in Eq. (7), in which A denotes a positive definite matrix:

$$\hat{\gamma}(\tau) = \arg\min_{\gamma} \eta(\tau,\gamma)' \cdot A \cdot \eta'(\tau,\gamma). \tag{7}$$

Table 1
Data definitions, sources, and descriptive statistics of the variables.

Variable	Definition	Source	Obs	Mean	Std	Min	Max
Solar	Installed solar energy capacity (gigawatts)	Statistical review of world energy	1012	1.92	9.21	0	175.01
Wind	Installed wind energy capacity (gigawatts)	Statistical review of world energy	902	1.32	15.14	0	453
Geothermal	Installed geothermal energy capacity (gigawatts)	Statistical review of world energy	361	530.14	852.01	0	3811.82
Climate change variables							
GHG	Total greenhouse gases emissions, measured in million tons of 'carbon dioxide-equivalents'	Statistical review of world energy	1012	7.04e8	1.57e9	2.80e5	1.16e10
CO2	CO2 emissions (million tons)	World Bank	1012	7.36	4.92	0.67	35.91
Extreme_N	Extreme temperature events (number)	International disasters database	1012	0.11	0.37	0	3
Extreme_L	Total loss caused by extreme temperature	International disasters database	1012	6.21e3	1.39e5	0	4.28e6
Drought_N	Drought events (number)	International disasters database	1012	0.08	0.31	0	3
Drought_L	Total loss caused by drought	International disasters database	1012	1.97e4	2.04e5	0	4.40e6
Flood_N	Flood events (number)	International disasters database	1012	0.78	1.32	0	10
Flood_L	Total loss caused by flood	International disasters database	1012	1.66e5	1.39e6	0	3.17e7
Control variables							
Policy	National policy on renewable energy	International energy agency	1012	0.17	0.37	0	1
Popu	Total population		1012	1.04e8	2.57e8	2.54e6	1.39e9
Rent	Total natural resource rents (% of GDP)	Statistical review of world energy	1012	17.11	15.62	0.06	65.38
GDP	Real gross domestic product (constant 2010 US$)	World Bank	1012	1.23e12	2.43e12	9.16e9	1.79e13
Trade	Merchandise trade (% of GDP)	World Bank	1012	66.44	37.86	12.31	192.12
Energy	Renewable energy consumption (% of total)	Statistical review of world energy	1012	17.10	15.62	0.06	65.38
EI Nino	EI Nino years	El Niño and La Niña Years and Intensities	1012	0.17	0.38	0	1

4. Empirical results

4.1. Preliminary analysis

As clean energy investments include the installed capacities of solar (*Solar*), wind (*Wind*), and geothermal (*Geothermal*) energy, we investigate the effects of climate change on *Solar*, *Wind*, and *Geothermal*, separately.

4.1.1. The effects of climate change on solar investment

The results of quantile regression estimation are shown in Table 2. The panel fixed effect estimate is also presented for comparison. We first analyze the impact of climate change on solar investment in the panel fixed effects model. Table 2 shows that *GHG* is positive and statistically significant at the 10% level, while the variables *Extreme_L*, *Drought_L*, and *Flood_L* are negative and statistically significant at the 10% level. The results mean that greenhouse gas emissions increase the investment in solar energy, but extreme temperature and extreme weather events produce negative impacts on solar investment.

It should be noted that the statistical significance of climate change across different quantiles varies quite a bit in the distribution. Specifically, the variable *GHG* is statistically insignificant in the 0.1 and 0.25 quantiles, while the coefficient turns positive and statistically significant at the 10% level in 0.5–0.9 quantiles. Indicating that the impact of greenhouse gas on solar investment depends on the development of solar energy in a country. Greenhouse gases tend to promote solar investment in countries that have higher solar investment, while restrains it in countries with lower solar investment. This finding is different from previous literature, which suggest that greenhouse gas emissions stimulate solar energy investment (Schnitzer et al., 2007). The reasons may be that countries with larger solar investment have benefitted a lot from solar energy and try to reduce greenhouse gas emissions through promoting solar investment when they are faced with an increasing greenhouse effect (Pan et al., 2004). However, this effect does not appear in countries with lower solar investment, as the cost of solar energy is

Table 2
Quantile regression estimation results for solar investment.

	OLS	Quantiles				
		0.1	0.25	0.5	0.75	0.9
GHG	1.496*	−0.0681	−0.0365	0.2272*	0.328***	2.178***
	(0.790)	(0.1037)	(0.0287)	(0.1301)	(0.0454)	(0.0945)
Extreme_L	−0.247*	0.249	−0.0322	−0.682***	−1.670***	−6.624***
	(0.144)	(0.289)	(0.0228)	(0.0099)	(0.0346)	(0.0107)
Drought_L	−0.241*	−0.377	−0.0961	−1.159	−2.225***	−3.137***
	(0.145)	(0.5671)	(0.1325)	(1.0388)	(0.0533)	(0.0589)
Flood_L	−0.842**	−0.055	−0.058	−0.871***	−0.711***	−1.659***
	(0.273)	(0.0431)	(0.1137)	(0.0184)	(0.180)	(0.0519)
Gdp	14.05***	0.0111***	0.142***	0.944***	2.433***	5.293***
	(1.560)	(0.0090)	(0.0075)	(0.0630)	(0.107)	(0.0999)
Popu	11.8***	0.0029***	0.0685***	0.685***	0.772***	5.144***
	(3.004)	(0.0007)	(0.0172)	(0.0311)	(0.0486)	(0.130)
Rent	0.339*	0.0012	−0.0172	−0.235***	−0.071***	0.075***
	(0.151)	(0.0114)	(0.2017)	(0.0265)	(0.0060)	(0.0203)
Energy	0.135*	−0.0085	−0.0088	−0.022***	−0.032***	−0.153***
	(0.077)	(0.1029)	(0.0072)	(0.0024)	(0.0014)	(0.0065)
Trade	0.231***	0.0040***	0.0050***	0.0357***	0.101***	0.119***
	(0.0206)	(0.0011)	(0.0007)	(0.0028)	(0.0011)	(0.0022)
Policy	0.166***	2.978***	0.641***	6.419***	14.16***	54.56***
	(0.075)	(0.0001)	(0.0059)	(0.0580)	(0.0864)	(0.4490)

Notes: OLS indicates panel fixed effects' regression estimation. Standard errors are in parentheses. *, **, and *** mean statistical significance at the 10%, 5%, and 1% levels, respectively.

much higher than that of traditional energy technologies (Timilsina et al., 2012). These countries will not invest in solar energy on account of greenhouse gas emissions, and the effect of greenhouse gases on solar investment is insignificant.

The variables *Extreme_L*, *Drought_L*, and *Flood_L* show differentiated influences on solar investment across different quantiles in the distribution. These variables produce statistically insignificant impacts on solar investment at the 10% level in the 0.1 and 0.25 quantiles and statistically significantly negative impacts in the 0.75 and 0.9 quantiles. They suggest that extreme temperature and weather events tend to decrease solar investment in countries with greater solar investment, while there is no such inhibition in countries whose solar investment is lower. The reason may be that extreme temperature and weather events may damage the equipment of solar energy, resulting in serious losses to solar investors, which may reduce confidence in solar investment. Existing literature, such as Wang et al. (2020b) and Huang and Zheng (2020) also hold the opinion that extreme disasters produce a negative impact on investors' confidence, but the heterogeneity of previous investment has not been studied in that literature.

When turning to control variables, the variable *GDP* is positive and statistically significant at the 1% level in all quantiles of the distribution, the result is similar with that of panel fixed effects model. Our results indicate that economic development is conducive to solar investment, which is in line with Dreveskracht (2013). *Popu* is also positive and statistically significant at the 1% level in all quantiles of the distribution. One reason accounting for this is that a larger population demands a greater amount of energy consumption and better environmental quality, which spur solar energy investment for its fewer polluting emissions. The coefficients of *Trade* and *Policy* are positive, which are both statistically significant at the 1% level in all quantiles of the distribution, indicating that trade may help improve the operational technology of clean energy, thus promoting solar energy investment. Policies on clean energy are effective in promoting solar investment, which is similar to the findings of Polzin et al. (2015).

It appears that the variables *Rent* and *Energy* produce differentiated effects along with the different levels of solar investment. The effect of *Rent* is statistically insignificant in the 0.1–0.5 quantiles, but it turns positive and statistically significant at the 10% level in the 0.75 and 0.9 quantiles, meaning that the cost of natural resources tends to promote solar investment in countries with higher solar investment, but has little impact in countries with lower solar investment. The coefficient of *Energy* is statistically insignificant in the 0.1–0.5 quantiles, but becomes positive and statistically significant at the 10% level in the 0.75 and 0.9 quantiles, implying that the proportion of clean energy consumption raises solar energy investment just in countries with higher solar investment. The reason may be similar to that of greenhouse gases.

4.1.2. The effects of climate change on wind investment

To evaluate how climate change affects wind energy investment in greater detail, we look to solve this problem through quantile regression estimation. Similarly, we present the results of the panel fixed effect estimate for comparison. The results are shown in the upper part of Table 3. Since the effects of the control variables are similar to those for solar investment, we do not report the effects of control variables during the analysis of wind and geothermal investments in the following tables.

As can be seen from the panel fixed effects model, the effect of *GHG* on wind investment is negative and statistically significant at the 5% level, while the coefficients of *Extreme_L*, *Drought_L*, and *Flood_L* are negative and statistically significant at the 10% level, which is different from that of solar investment. It is worth noticing that the effects of *GHG* on wind investment are negative and they are statistically significant at the 1% level in 0.1–0.9 quantiles, which is different from the effects on solar investment. One possible reason is that it is a controversial topic for how wind energy consumption affects greenhouse gas emissions. Some researchers have analyzed the nexus of wind energy and greenhouse gases emissions, and the results show that there is no evidence that proves wind energy helps reduce the emissions of greenhouse gases (Kuşkaya and Bilgili, 2020). Therefore, when faced with global warming, decision-makers will not consider reducing greenhouse gas emissions by investing in wind energy.

The effects of *Extreme_L*, *Drought_L*, and *Flood_L* on wind investment are statistically insignificant in the 0.1–0.5 quantiles, but the effects are negative and they are statistically significant at the significance 10% level in the 0.75 and 0.9 quantiles. The results show that extreme temperature and weather events will inhibit wind investment in countries with greater wind investment, which is the same as the effects of extreme temperature and weather events on solar investment, thus providing further evidence that extreme disasters will produce a negative impact on investors' confidence and inhibit investment in clean energy (Wang et al., 2020b).

Table 3
Quantile regression estimation results for wind and geothermal investment.

	OLS	Quantiles				
		0.1	0.25	0.5	0.75	0.9
Wind investment						
GHG	−2.655**	−0.0500***	−0.1190***	−0.4250***	−0.5560***	−0.2160***
	(0.982)	(0.0010)	(0.0252)	(0.0051)	(0.0074)	(0.0225)
Extreme_L	−1.140***	0.0664	0.0274	−0.1020***	−0.5590***	−1.2150***
	(0.3320)	(0.1031)	(0.0220)	(0.0033)	(0.0011)	(0.0048)
Drought_L	−0.791*	0.0026	−0.0048	−0.0696***	−0.0206***	−0.130***
	(0.3320)	(0.1001)	(0.4022)	(0.0040)	(0.0062)	(0.0048)
Flood_L	−1.110**	0.0029	−0.0086	−0.0220	−0.0100***	−0.297***
	(0.3470)	(0.0021)	(0.0064)	(0.0121)	(0.0028)	(0.0093)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Geothermal investment						
GHG	0.475**	0.150***	0.0887***	0.561***	1.915***	4.300**
	(0.169)	(0.0012)	(0.0026)	(0.0740)	(0.270)	(1.631)
Extreme_L	−0.0497*	−0.0077***	−0.0068*	−0.0247***	−0.0026	0.958
	(0.0299)	(0.0012)	(0.0029)	(0.0002)	(0.0372)	(1.062)
Drought_L	−0.1300*	−0.0590***	−0.0148*	1.724***	0.971***	−0.222
	(0.0664)	(0.0012)	(0.0089)	(0.0033)	(0.0168)	(0.263)
Flood_L	0.253**	−0.0259***	−0.0326***	0.956***	1.045***	1.209
	(0.0869)	(0.0029)	(0.0036)	(0.0042)	(0.189)	(1.020)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS indicates panel fixed effects' regression estimation. Standard errors are in parentheses. *, **, and *** mean statistical significance at the 10%, 5%, and 1% levels, respectively.

4.1.3. The effects of climate change on geothermal investment

We similarly utilize quantile regression estimation to investigate the effect of climate change on geothermal energy investment and employ the panel fixed effect model for comparison. The empirical results are shown in the bottom part of Table 3.

At the bottom part of Table 3 we find that the coefficient of *GHG* is positive, while the coefficients of *Extreme_L*, *Drought_L*, and *Flood_L* are negative, all the coefficients are statistically significant at 10% level in the panel fixed effects model. This indicates that greenhouse gas emissions are conducive to promoting geothermal investment while extreme temperature and extreme weather events will inhabit it. The results are similar to the effects of these variables on solar and wind energy investment.

The effects of *GHG* on geothermal investment are positive and they are statistically significant at the 1% level in all quantiles, which is different from the effects of greenhouse gases on solar and wind investments. As geothermal energy emits particularly low greenhouse gases into the atmosphere, it is denoted as being environmentally friendly (Rybach, 2003). Therefore, geothermal energy is considered to be an effective means to reduce greenhouse gas emissions in countries regardless of the investment level of geothermal energy. The effects of *Extreme_L*, *Drought_L*, and *Flood_L* on geothermal investment are negative and they are statistically significant at the 10% significance level in the 0.1–0.5 quantiles, but the effects are statistically insignificant in the 0.9 quantiles. The results show that extreme temperature and weather events will inhibit geothermal investment in countries with less wind investment, but could barely influence geothermal investment in countries with greater geothermal investment. Table 4 presents a brief empirical summary of solar, wind, and geothermal investments for comparison. As seen from Table 4, we conclude that three forms of climate change produce varying effects on different kinds of clean energy investment. Greenhouse gas emissions are conducive to promoting solar investment in countries with greater solar investment, helping to increase geothermal investment in all quantiles, whereas the effects on wind investment are negative. Extreme temperatures and extreme weather events cause similar effects on solar and wind investment, but the effects on geothermal investment are different.

4.2. Empirical analysis of heterogeneity

4.2.1. Heterogeneity in different development levels

In order to investigate whether the shocks of climate change on clean energy investment exist heterogeneity, that is, whether there are significant differences in different development levels, we conduct analysis for sub-samples. Since OECD countries show substantial heterogeneity versus other countries, the full sample is divided into subsamples of OECD countries and non-OECD countries (Zheng et al., 2019). The re-estimated results for countries of different regions are shown in Tables 5-7.

Comparing Tables 5-7, we find that the effects of climate change on clean energy investment show significant heterogeneity between OECD and non-OECD countries. More specifically, the effects of greenhouse gases on solar and geothermal energy investments are positive and they are statistically significant at the 1% level in almost all quantiles of the distributions in OECD countries, while the effects are negative and statistically significant in non-OECD countries. This indicates that OECD countries care more about global warming and try to reduce greenhouse gases via clean energy, but non-OECD countries have not paid as much concern about greenhouse gases as OECD countries. However, the effects of greenhouse gases on wind investment are negative in both OECD and non-OECD countries, which are similar to those of the whole sample.

Table 4
Overview about the results.

Group	Solar		Wind		Geothermal	
Quantile	Lower	Upper	Lower	Upper	Lower	Upper
GHG	×	+	−	−	+	+
Extreme_L	×	−	×	−	−	×
Drought_L	×	−	×	−	−	×
Flood_L	×	−	×	−	−	×
Gdp	+	+	+	+	+	+
Popu	+	+	+	+	+	+
Rent	×	+	+	+	×	+
Energy	×	+	×	+	×	+
Trade	+	+	+	+	×	×
Policy	+	+	+	+	+	+

Notes: + represents a positive and statistical impact. - represents a negative and statistically significant impact. × represents a statistically insignificant impact.

Table 5
Re-estimation results for solar investment: subsamples.

Quantile	0.1	0.25	0.5	0.75	0.9
OECD countries					
GHG	0.931***	0.376***	0.612***	3.299***	3.454***
	(0.125)	(0.0475)	(0.049)	(0.243)	(0.671)
Extreme_L	−0.0417**	−0.081***	−1.384***	−3.071***	−9.752***
	(0.0139)	(0.0116)	(0.0333)	(0.104)	(0.128)
Drought_L	−0.317***	−0.102***	−1.782***	−2.751***	−0.363*
	(0.0329)	(0.00664)	(0.170)	(0.138)	(0.209)
Flood_L	−0.456***	−0.211***	−2.213***	−2.426***	−8.731***
	(0.0878)	(0.0107)	(0.244)	(0.129)	(0.476)
Control variables	Yes	Yes	Yes	Yes	Yes
non-OECD countries					
GHG	−2.8715	0.8691	0.1402	−0.3910***	−1.2022***
	(1.6981)	(0.8816)	(0.2541)	(0.0466)	(0.136)
Extreme_L	−7.1115	0.0025	−0.1440***	−0.3400***	−1.2162***
	(4.3715)	(1.2116)	(0.0053)	(0.0208)	(0.1041)
Drought_L	−1.0801	−0.2081	−1.4370***	−0.3720***	−1.6670***
	(2.9615)	(2.1316)	(0.0117)	(0.0213)	(0.0396)
Flood_L	−0.6822	8.3715	−0.549***	−0.226***	−0.917***
	(1.9315)	(5.2816)	(0.0105)	(0.0324)	(0.0630)
Control variables	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. *, **, and *** mean statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 6
Re-estimation results for wind investment: subsamples.

Quantile	0.1	0.25	0.5	0.75	0.9
OECD countries					
GHG	−0.0340***	−0.0354***	−0.174***	−0.0845***	−1.068***
	(0.0004)	(0.0084)	(0.0212)	(0.0171)	(0.0591)
Extreme_L	0.0653	−0.0050	−0.2444	−0.645***	−1.535***
	(0.0769)	(0.0935)	(0.1041)	(0.0087)	(0.0081)
Drought_L	−0.0117***	−0.0007**	−0.225***	−0.618***	−1.543***
	(0.0002)	(0.0003)	(0.0033)	(0.0251)	(0.0088)
Flood_L	−0.0012***	−0.0675***	−0.1320***	−0.1210***	−0.1050***
	(0.0007)	(0.0036)	(0.0091)	(0.0097)	(0.0092)
Control variables	Yes	Yes	Yes	Yes	Yes
non-OECD countries					
GHG	−0.0308***	−0.0841***	−0.376***	−1.113***	−1.521***
	(0.0043)	(0.0004)	(0.0008)	(0.0045)	(0.0057)
Extreme_L	0.0145***	0.0101***	0.0125***	0.00247**	−0.0039***
	(0.0021)	(0.00197)	(0.0048)	(0.0007)	(0.0003)
Drought_L	−0.0271***	−0.0011***	−0.0021***	−0.0113***	−0.0018*
	(0.0035)	(0.0001)	(0.0002)	(0.0007)	(0.0011)
Flood_L	−0.0691***	−0.0005*	−0.0164***	−0.00144*	−0.0148***
	(0.0029)	(0.0003)	(0.0001)	(0.0006)	(0.0006)
Control variables	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. *, **, and *** mean statistical significance at the 10%, 5%, and 1% levels, respectively.

One point that needs special attention is that the effect of extreme temperature on geothermal investment is positive and they are statistically significant at the 10% level in 0.1–0.9 quantiles of the distributions in OECD countries, which is different from the results in non-OECD countries and the full sample. A possible reason is that extreme temperatures increase the motivation to utilize natural heat; i.e., geothermal energy in the countries with strong economic development. Except for greenhouse gases, extreme temperature, and extreme weather events produce negative effects on clean energy investment in both OECD and non- OECD countries, which are similar to the results of the full sample.

Table 7
Re-estimation results for geothermal investment: subsamples.

Quantile	0.1	0.25	0.5	0.75	0.9
OECD countries					
GHG	3.7520***	4.0320***	7.5040***	4.8910***	3.9520***
	(0.0013)	(0.0551)	(0.0239)	(0.1330)	(0.0486)
Extreme_L	0.1720***	0.123***	0.337***	0.131***	0.212***
	(0.0052)	(0.0257)	(0.0683)	(0.0361)	(0.0317)
Drought_L	−1.5200***	−1.497***	−0.518***	−0.2201***	−0.0547***
	(0.0154)	(0.1721)	(0.0163)	(0.0113)	(0.0104)
Flood_L	−0.142***	−0.0120***	−0.0444***	−0.1220***	−0.2950***
	(0.0848)	(0.0014)	(0.0149)	(0.0323)	(0.0244)
Control variables	Yes	Yes	Yes	Yes	Yes
non-OECD countries					
GHG	−0.0129***	−0.1970***	−7.022***	−6.220***	−3.5025*
	(0.0002)	(0.0101)	(0.472)	(0.110)	(1.6505)
Extreme_L	−0.0476***	−0.260***	−0.583***	−0.607***	−6.2511*
	(0.000140)	(0.0112)	(0.0307)	(0.0178)	(3.5153)
Drought_L	−0.2040***	−2.307***	−1.4560***	−2.0710***	−4.0396***
	(0.0056)	(0.0167)	(0.239)	(0.0282)	(1.2103)
Flood_L	−0.3850***	−2.0310***	−1.9550***	−1.3950***	−5.1968**
	(0.0137)	(0.0204)	(0.1120)	(0.0169)	(2.4164)
Control variables	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. *, **, and *** mean statistical significance at the 10%, 5%, and 1% levels, respectively.

4.2.2. Heterogeneity during EI Nino years

As extreme weather events increase in frequency and intensity during EI Nino years, there may be some differences among the impacts of climate change on clean energy investment during those periods. The re-estimated results taking EI Nino years into consideration appear in Tables 8.

Table 8 presents that the coefficients and significance levels of *GHG*, *Extreme_L*, *Drought_L*, and *Flood_L* are similar to those results in Tables 2-3, indicating that when taking EI Nino as a control variable, the effects of climate change on clean energy investment are consistent. The coefficients of *EI Nino* are positive and statistically significant at the 1% level in all quantiles of the distributions under analyses of solar, wind, and geothermal investments. The results illustrate that when EI Nino occurs, it does in fact produce a positive impact on clean energy investment, but the effects of climate change on clean energy investment do not greatly differ due to the occurrence of EI Nino. The reason may be that with the increasing frequency of EI Nino, people may pay more attention to environmental protection and firms will seek to reduce environmental pollution by investing in clean energy (Gonzales et al., 2014).

Table 8
Quantile regression estimation results: Taking EI Nino into consideration.

	OLS	Quantiles				
		0.1	0.25	0.5	0.75	0.9
Solar investment						
GHG	−1.540***	0.0012	0.0960	0.0235***	0.3740***	1.8360***
	(0.459)	(0.0082)	(0.0721)	(0.0047)	(0.0095)	(0.0499)
Extreme_L	−0.2760*	0.0249	0.0275	−0.8730***	−1.8080***	−0.5670***
	(0.0255)	(0.0321)	(0.0913)	(0.0676)	(0.0626)	(0.0308)
Drought_L	−0.2220***	−0.3770	−0.0710	−1.4450***	−2.5780***	−2.9710***
	(0.0251)	(0.4512)	(0.0617)	(0.0543)	(0.0207)	(0.1100)
Flood_L	−0.8520*	−0.5050	0.1370	−0.9490***	−1.0540***	−1.5810**
	(0.2720)	(0.3871)	(0.7040)	(0.0301)	(0.0651)	(0.0515)
EI Nino	0.4730*	0.0835***	0.0675***	1.2990***	1.1800***	2.5420***
	(0.2590)	(0.0064)	(0.0065)	(0.0574)	(0.1450)	(0.2050)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Wind investment						
GHG	−2.796***	−0.0470***	−0.1470***	−0.3780***	−0.5830***	−0.1510***
	(0.979)	(0.0101)	(0.0202)	(0.0280)	(0.0142)	(0.0590)
Extreme_L	−1.2030***	−0.0660	−0.0263	−0.1180***	−0.5730***	−1.2330***
	(0.3310)	(0.0980)	(0.0341)	(0.0116)	(0.1301)	(0.1410)
Drought_L	−0.7640*	−0.0217	−0.0095	−0.0954***	−0.0698***	−0.1330***
	(0.3300)	(0.0480)	(0.0491)	(0.0084)	(0.0136)	(0.0233)
Flood_L	−1.1290***	−0.0075	0.0123	−0.0063	−0.0524***	−0.3230***
	(0.3460)	(0.0190)	(0.0462)	(0.0059)	(0.0012)	(0.0049)
EI Nino	0.9410	0.0042***	0.0047***	0.0603***	0.0813***	0.1740***
	(0.3340)	(0.0003)	(0.0007)	(0.0106)	(0.0035)	(0.0059)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Geothermal investment						
GHG	0.4870***	0.1500***	0.1020***	0.5071***	1.2670***	0.8282***
	(0.1690)	(0.0021)	(0.0013)	(0.0365)	(0.2070)	(0.1960)
Extreme_L	0.0474	−0.0093**	−0.0065*	−0.0263***	0.0133	−0.4395
	(0.0861)	(0.0042)	(0.0038)	(0.0036)	(0.0639)	(1.0413)
Drought_L	−0.1300	−0.0580***	−0.0304***	−1.7350	0.9550	0.1387
	(0.0863)	(0.0019)	(0.0073)	(1.1033)	(1.0309)	(0.3292)
Flood_L	−0.2590***	−0.0166***	−0.0279***	−0.9810	1.0480	1.4349
	(0.0869)	(0.0029)	(0.0037)	(0.8686)	(0.9899)	(1.0298)
EI Nino	0.1220*	0.0096***	0.0091***	0.0784***	0.1050***	0.3967***
	(0.0703)	(0.0026)	(0.0017)	(0.0018)	(0.0191)	(0.0935)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS indicates panel fixed effects' regression estimation. Standard errors are in parentheses. *, **, and *** mean statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 9
Quantile regression estimation results for solar investment: a different climate change index.

	OLS	Quantile				
		0.1	0.25	0.5	0.75	0.9
CO2	1.152***	−0.0330	−0.0392	0.0823***	0.5850***	0.1270***
	(0.347)	(0.0193)	(0.0212)	(0.0171)	(0.0083)	(0.0351)
Extreme_N	−0.413**	−0.0110	0.0253	−0.182***	−0.0052***	−0.852***
	(0.1960)	(0.0999)	(0.0730)	(0.0502)	(0.0015)	(0.0840)
Drought_N	−0.309***	0.0332	−0.0017	−0.6180***	−0.1530***	0.6170**
	(0.0271)	(0.0194)	(0.0076)	(0.0661)	(0.0145)	(0.1905)
Flood_N	−0.277***	−0.1480	−0.0902	−0.2460**	−0.9450***	−3.6460***
	(0.0322)	(0.1470)	(0.1105)	(0.0870)	(0.0264)	(0.1660)
Gdp	17.410***	0.3290***	0.3170***	2.0140***	3.6020***	6.1710***
	(1.8040)	(0.0008)	(0.0034)	(0.0189)	(0.0352)	(0.2520)
Popu	18.37***	0.126***	0.1040***	0.4760***	0.2070***	4.6340***
	(3.552)	(0.0021)	(0.0033)	(0.0458)	(0.0190)	(0.2410)
Rent	0.3670*	0.0014	0.0102	0.0674	0.0105***	0.0016***
	(0.1500)	(0.0234)	(0.0943)	(0.1137)	(0.0005)	(0.0002)
Energy	0.0884***	−0.0035	−0.0026	0.0244***	0.0504***	0.0620***
	(0.0092)	(0.0357)	(0.0469)	(0.0026)	(0.0011)	(0.0070)
Trade	0.0471*	0.0067***	0.0083***	0.0481***	0.1120***	0.1050***
	(0.0220)	(0.0005)	(0.0001)	(0.0007)	(0.0011)	(0.0043)
Policy	0.4590***	2.7910***	0.6880***	6.3380***	14.280***	56.430***
	(0.0575)	(0.0020)	(0.0043)	(0.0734)	(0.0234)	(0.2070)

Notes: OLS indicates panel fixed effects' regression estimation. Standard errors are in parentheses. *, **, and *** mean statistical significance at the 10%, 5%, and 1% levels, respectively.

4.3. Robustness tests

To investigate whether our empirical results are reliable, then we re-estimate the model using different indices for climate change. As carbon dioxide is the main component of GHG, global average temperatures increase with carbon dioxide emissions, and the trend of global warming remains approximately constant (Solomon et al., 2009), we use carbon dioxide emissions to represent GHG emissions. Referring to Chen and Chang (2020), the number of extreme temperature, drought, and flood events is employed to represent the indicators of climate change. The re-estimated results are shown in Tables 9-10. Comparing the empirical results in Tables 9-10 with the empirical results in Tables 2-3, we find that the results are nearly the same, indicating that the results are robust.

5. Conclusions and policy suggestions

5.1. Conclusions

This research investigates the shocks of climate change on clean energy investment using panel data of 44 countries during 1996 to 2018. This study focuses on whether countries with greater and lesser clean energy investment respond similarly to climate change. Thus, a quantile regression model is employed to conduct the parameter estimation for the entire sample and to examine the heterogeneity of OECD and non-OECD countries. As the data of clean energy investment can be obtained mainly for solar, wind, and geothermal energy, we examine the effects of climate change on these three types, respectively. Based on the empirical results, we arrive at several main conclusions.

Table 10
Quantile regression estimation results for wind and geothermal investment: a different climate change index.

	OLS	Quantiles				
		0.1	0.25	0.5	0.75	0.9
Wind investment						
CO2	−2.346***	−0.0050***	−0.0626***	−0.2250***	−0.4260***	−0.2650***
	(0.459)	(0.0001)	(0.0003)	(0.0007)	(0.0021)	(0.0130)
Extreme_N	−0.0468*	0.0003	0.0021	−0.0184***	−0.0062***	−0.0300***
	(0.0343)	(0.0003)	(0.0041)	(0.0004)	(0.0015)	(0.0074)
Drought_N	−555.5***	0.0020	0.00267	−0.0485***	−0.0660***	−0.378***
	(104.2)	(0.0012)	(0.0059)	(0.0013)	(0.0020)	(0.0148)
Flood_N	−0.0640*	0.0059	0.0025	−0.0120***	−0.0030***	−0.0117**
	(0.0330)	(0.0171)	(0.0532)	(0.0015)	(0.0006)	(0.0039)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Geothermal investment						
CO2	1.164***	0.0807***	0.0809***	0.4460***	2.2310***	1.0610***
	(0.178)	(0.0101)	(0.0023)	(0.0045)	(0.0103)	(0.2379)
Extreme_N	−0.161***	−0.0573***	−0.0497***	−0.0413***	0.4850	2.8980
	(0.0169)	(0.0148)	(0.0044)	(0.0116)	(0.3211)	(7.4910)
Drought_N	−0.2520*	−0.0326*	−0.0356***	1.4660***	0.1570	8.888
	(0.1030)	(0.0137)	(0.0053)	(0.0097)	(0.1980)	(20.270)
Flood_N	−0.1200***	−0.0013	−0.00739	−1.1140***	2.2350***	6.654
	(0.0115)	(0.0774)	(0.0374)	(0.0092)	(0.0390)	(14.82)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS indicates panel fixed effects' regression estimation. Standard errors are in parentheses. *, **, and *** mean statistical significance at the 10%, 5%, and 1% levels, respectively.

The effects of climate change on clean energy investment vary significantly in countries with greater and lesser clean energy investment. More specifically, greenhouse gases may promote solar investment in countries with greater solar investment, but the effect in countries with lesser solar investment is statistically insignificant. Similarly, extreme temperature, drought, and flood produce significantly negative influences on solar and wind investments in countries with greater investment, but the impacts in countries with lesser investment are statistically insignificant. In addition, the effects of greenhouse gases on solar and geothermal investments are significantly positive, while they are significantly negative on wind investment. One possible reason is that solar and geothermal energies are considered to be effective in reducing greenhouse gas emissions, while whether or not wind energy can reduce greenhouse gas emissions remains controversial.

There exist significant differences in the impacts of socioeconomic factors on clean energy investment. Economic development, population, clean energy consumption, and clean energy policy are conductive to investments in solar, wind, and geothermal energies for all quantiles of the distribution. Natural resource rents produce significantly positive effects on investments in the three energies only at the upper quantiles. Trade can promote solar and wind energy investments significantly, but the effect on geothermal energy investment is insignificant.

Specifically, EI Nino has a positive effect toward clean energy investment. When EI Nino occurs, people likely pay more attention to environmental problems and promote investment in clean energy as an effective means to mitigate environmental pollution.

Finally, the effects of climate change on clean energy investment show significant heterogeneity in the subsamples of OECD and non-OECD countries. Specifically, greenhouse gases are significantly positive at promoting solar, wind, and geothermal energy investments in OECD countries, while their effects are negative in non-OECD countries. The reason may be that the technology of clean energy is more advanced in OECD countries than that in non-OECD countries. Extreme temperatures and extreme weather events produce similar effects in both OECD and non- OECD countries.

5.2. Policy suggestions

According to the analyses above, some policy implications and suggestions can be drawn as follows.

First, authorities can propagate the practices of some OECD countries and encourage countries with less clean energy investment to use them as a reference. Empirical results show that GHG are significantly positive at increasing clean energy investment in OECD countries, indicating that these countries concentrate more on the problem of global warming and seek ways to reduce GHG emissions. As countries with greater clean energy investment tend to care more about climate change and promote clean energy investment, some policies, such as subsidies for clean energy investment, should be initiated to encourage countries to increase clean energy investment.

Second, carry out differentiated clean energy plan based on the specific environment. According to the diversified exploration about the shocks of climate change on clean energy investment, climate change produces different effects on solar, wind and geothermal investment. Moreover, the impacts of climate change on clean energy investment vary significantly in countries with the development levels of clean energy investment. Therefore, governments should carry out differentiated clean energy plan based on the environment of countries.

Third, governments should continue to implement policies on clean energy and encourage residents to use various forms of clean energy. Policies on clean energy and clean energy consumption are effective at promoting clean energy investment. If countries continue to implement policies on clean energy and encourage residents to use clean energy instead of traditional energy, then this will significantly inhibit global warming.

Finally, industry can target to develop clean energy equipment to deal with the damage caused by extreme weather events. Drought and flood produce significantly negative effects on clean energy investment. One reason may be that extreme weather events can damage clean energy equipment and reduce investment confidence in this sector. Thus, how to overcome this problem is of vital importance for investment in clean energy.

Credit author statement

Xia Chen: Conceptualization; Data curation; Formal analysis; Writing - original draft.

Qiang Fu: Investigation; Methodology; Resources; Software.

Chun-Ping Chang: Project administration; Supervision; Writing - review & editing.

Table A1
Country list.

Solar investment	
OECD	Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Japan, Mexico, Netherlands, Norway, Portugal, Slovakia Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States
Non-OECD	Algeria, Brazil, Bulgaria, China, Egypt, Honduras, India, Jordan, Malaysia, Pakistan, Philippines, Romania, Russia, South Africa, South Korea, Thailand, Ukraine, United Arab Emirates
Wind investment	
OECD	Australia, Austria, Belgium, Canada, Chile, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Turkey, United Kingdom, United States
Non-OECD	Brazil, Bulgaria, China, Egypt, India, Iran, Morocco, Pakistan, Philippines, Romania, Russia, South Africa, South Korea, Thailand, Tunisia, Uruguay
Geothermal investment	
OECD	Austria, Chile, France, Germany, Italy, Japan, Mexico, New Zealand, Portugal, Turkey, United States
Non-OECD	China, Guatemala, Indonesia, Kenya, Nicaragua, Papua New Guinea, Philippines, Russia

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2021.105136.

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