The impact of temperature shocks on energy poverty: Findings from rural China

Hongxu Shi
School of Agricultural Economics and Rural Development
Renmin University of China

Kelin Chen
School of Agricultural Economics and Rural Development
Renmin University of China

Jun Zhang*
School of Agricultural Economics and Rural Development
Renmin University of China

Selected Paper prepared for presentation at the 2024 Agricultural & Applied Economics Association Annual Meeting, New Orleans, LA; July 28-30, 2024

---

*Corresponding auther. Email: junzhang@ruc.edu.cn

Abstract

In the context of global climate change, understanding the relationship between climate change and energy poverty is an increasingly urgent matter and an effective way to combat both issues. Consequently, this study investigates the impacts of temperature shocks on energy poverty among rural Chinese households. Data from the China Family Panel Studies (CFPS) and NASA were utilized and findings indicate that temperature shocks lead to increased energy poverty. When different indicators of temperature shocks are substituted, the conclusions do not change. Rural households in northern China and remote areas far from the provincial capital are most susceptible to temperature shocks in terms of energy poverty. Additionally, temperature shocks have long-term effects on energy poverty. Therefore, we propose several recommendations for ameliorating energy poverty in the context of environmental change.

Keywords: Temperature shocks; Energy poverty; Impact assessment; China Family Panel Studies

1. Introduction

The 17 Sustainable Development Goals (SDGs) focus on the fundamental pillar of the United Nations' 2030 Agenda for Sustainable Development, which serves as a "common blueprint for peace and prosperity for people and the planet" (United Nations, 2021). Since its introduction, these aims have driven many governmental efforts, business policies, educational pursuits, and research activities. This study shares the same objective, as it fits the goals of reducing energy poverty and climate risk (SDGs 7 and 13).

Climate change has led to global warming, which has increased the frequency and severity of extreme temperatures, leading to an increase in mortality and morbidity from epidemics (Deschênes & Greenstone, 2011; McDermott, 2022; McMichael, 2012;Xing et al., 2022; Zhou et al., 2022), health burdens (Cole et al., 2023; Jurgilevich et al., 2023), poverty (Carleton, 2017; Skoufias et al., 2011), and food insecurity (Chen & Gong, 2021; Li, 2012), among many other negative consequences (Awaworyi Churchill et al., 2022; Feeny et al., 2021). The effects of global warming on energy poverty, particularly in rural areas, have garnered little attention. This study posits that temperature shocks may exacerbate rural energy poverty. High temperatures increase the demand for energy, decrease labor productivity, and decrease agricultural income, all of which directly or indirectly contribute to household energy poverty. Energy poverty refers to a level of energy use that is insufficient to meet fundamental needs. Energy poverty can also be defined as the lack of access to appropriate, affordable, dependable, high-quality, safe, and environmentally friendly energy services to promote economic and human growth (C. P. Nguyen & Nasir, 2021). Energy poverty has negative effects on families, including increased mold contamination, worsened asthma, visual impairment, diminished cognitive ability, air pollution, and worsened health (Islam et al., 2022; Ravindra et al., 2021; Saenz et al., 2021; Sharpe et al., 2015). High temperatures may increase the likelihood of energy poverty for all households; for example, the occurrence of extreme heat increases the use of air conditioning, hence raising energy expenditure, and if air conditioners are not utilized, it leads to poorer labor productivity and lower total income (Feeny et al., 2021; Que et al., 2022). Extreme heat can reduce agricultural income, particularly in rural areas, because it can result in decreased agricultural production, increased pests and diseases, and difficulties in irrigation. Rural households dependent on agriculture are more susceptible to temperature shocks.

Recognizing energy poverty as a consequence of climate change is imperative for a more effective response to both climate change and the eradication of energy poverty. Rural regions are more susceptible to climate change and energy deprivation because of their reliance on agricultural production and a relatively underdeveloped energy infrastructure. Therefore, paying more attention to climate change and energy poverty in rural areas is important. In rural areas, extreme heat increases the use of air conditioners, which increases energy costs and, if unutilized, results in decreased labor productivity and total income. Extreme heat can also reduce agricultural income, because it can result in decreased agricultural yields, increased pests and diseases, and irrigation problems. Reduced income can prevent rural households from utilizing clean energy and heighten energy poverty. Existing research has focused primarily on how energy poverty affects climate change (Chakravarty & Tavoni, 2013; Ürge-Vorsatz & Tirado Herrero, 2012; Zhao et al., 2021), while little attention has been paid to the impact of climate change on energy poverty. Few studies have examined the short-term relationship between temperature and energy poverty over the short term (Awaworyi Churchill et al., 2022; Feeny et al., 2021). However, households may also engage in ex-ante avoidance and ex-post compensation behaviors in response to temperature shocks (Zivin et al., 2015). Long-term effects should consider these responses and may be a better way to expand pertinent research. Future research must consider this effect.

There are many advantages to selecting Chinese rural households for the study, as China is an ideal country for studying the impact of temperature shocks on energy poverty. First, China is the largest developing nation in the world, with a large number of rural households and degree of energy poverty in rural areas. China's rural households can serve as a case study for other developing nations seeking to combat climate change and eradicate energy poverty. Second, China is a large nation with abundant and variable meteorological data, making it an ideal location for scientific research. Third, the data from the China Family Panel Studies(CFPS) provide extensive household information that can be used to investigate the core themes of this study.

The contributions of this study are as follows. First, the principal component analysis (PCA) method was adopted to develop a household energy poverty index that objectively reflects the level of energy poverty in rural households. Second, we investigate the relationship between temperature shocks and energy poverty in rural China, which not only addresses the dearth of relevant research literature but also assists Chinese policymakers in developing short- and long-term strategies to reduce energy poverty from a climate change perspective. Third, to analyze the potential heterogeneity and asymmetry in the impact of temperature shocks on energy poverty, an analysis of households in different regions was conducted, which deepens the understanding of the existing literature.

The remaining sections are grouped as follows. Section 2 presents an overview of the relevant literature. Section 3 provides a summary of the data, variables, and empirical methodology. Section 4 discusses the importance of the empirical findings. Section 5 provides a summary of the study's results and policy suggestions.

2. Literature review

2.1. Temperature shocks may impact energy poverty via expenditures on energy

High-temperature shocks can cause energy poverty by increasing energy demand and consumption. (Alkire & Foster, 2011). Research indicates that extreme heat may increase the likelihood and severity of energy poverty (Campagnolo and De Cian, 2022; Falchetta and Mistry, 2021; Randazzo et al., 2020). According to Sanchez-Guevara et al. (2019), temperature shocks increase the likelihood of households experiencing energy poverty. This effect is more pronounced for low-income and low-quality housing households, and the incidence of energy poverty increases with the timing and frequency of temperature shocks caused by climate change. Temperature shocks result in increased energy consumption for cooling and higher energy bills, which can increase the probability of households falling into energy poverty (Bienvenido-Huertas et al., 2020). The increase in energy expenditure is divided into two categories: the energy consumption of air conditioning equipment to deal with high temperatures, and the installation of air conditioning equipment to deal with high temperatures, both of which exacerbate energy poverty among households (Mashhoodi, 2020). The global demand for indoor cooling is increasing owing to climate change and economic expansion. Frequent heat waves in Europe have increased the demand for air conditioners (ACs). Rising per capita incomes and economic growth in Asia and Africa have also boosted the demand for air conditioners, and the International Energy Agency has predicted that by 2050, the energy demand for indoor cooling will more than triple. As higher outdoor temperatures increase the amount of energy required for indoor cooling, temperature shocks exacerbate energy poverty. (Igawa et al., 2022). Air conditioners are extremely energy-intensive. China currently uses more than 15% of society's total electricity for cooling, which is 100 times more than the electricity used by electric cars in China. Thus, it is necessary to continue using empirical evidence to delve deeper into the impact of temperature shocks on energy poverty (Bienvenido-Huertas et al., 2021; Eichsteller et al., 2022; Maganga et al., 2021).

2.2. Temperature shocks may impact energy poverty via human capital

Due to climate change, extreme heat can detrimentally affect human capital. High temperatures might negatively impact labor productivity and mental health, subsequently reducing household income and augmenting the risk of energy poverty (Que et al., 2022; Gifford., 2016). Research indicates that for every 1°C increase of Wet Bulb Globe Temperature (WBGT), there is a corresponding decrease in construction workers' labor productivity by 0.57 and 0.33 percent, respectively (Li et al., 2016; Yi & Chan, 2017). In a 1.5 degree Celsius warming scenario by the end of the 21st century, farmers will lose 60% of their working hours in 2030 due to high temperatures, affecting the outdoor working population as a whole. These conditions are more severe in the southern region of China (Kjellstrom et al., 2019). High-temperature shocks can affect the mental and psychological health of the population (Liu et al., 2018). The decrease in food production caused by high temperatures and droughts can also increase farmers' psychological stress and even provoke suicidal tendencies (Carleton, 2017). For households with air conditioning, hot weather unquestionably increases the time spent on air conditioning, thereby increasing the proportion of the total household income spent on energy. These circumstances increased the likelihood of household energy poverty. It has been demonstrated that air conditioning can mitigate the negative effects of temperature shocks on labor productivity (Tang et al., 2016). If a household lacks air conditioning, it is more likely to experience a decline in labor productivity and thus fall back into a cycle of low-income and energy poverty. The heat wave that swept through Iraq in 2019, leaving people unable to sleep and perspiring continuously throughout the night, had a negative impact on their quality of life and productivity. This suggests that temperature shocks affect human capital, leading to energy poverty.

2.3. Temperature shocks may impact energy poverty via agricultural income

Numerous studies have demonstrated that temperature shocks negatively affect agricultural production (Matthews & Wassmann, 2003; Parry et al., 2004; Seo et al., 2005; Wu et al., 2006;

Yang, 2018). There is abundant evidence that extreme temperatures reduce crop yields (Aragón et al., 2021). The rural poor in developing countries are likely to be the most susceptible to temperature shocks. A study conducted in Australia demonstrated that frequent severe weather events caused by global warming have a significant and detrimental impact on agricultural productivity (Sheng et al., 2021). According to a study of 20 crops produced in Vietnam, changes in temperature can lead to marginal losses in agricultural productivity over the long and short term (C. T. Nguyen & Scrimgeour, 2022). According to a study of maize farming in Africa, high temperatures reduced yields in 65 percent of the territory, whereas dryness reduced yields across the entire continent (Lobell et al., 2011). A similar conclusion was reached in a study conducted in the United States where high temperatures diminished maize yield (Butler & Huybers, 2013). Studies on the relationship between wheat yield and temperature have revealed that extremely high temperatures are detrimental to wheat production, and that an increase in global average temperature and a 5% decrease in wheat yield are expected to reduce wheat yields by 30% by the mid-century (Lobell et al., 2012; Zaveri and Lobell, 2019). Chen and Gong (2021) examined the relationship between agricultural productivity and climate change and demonstrated that global warming poses a significant threat to agricultural productivity in China. Temperature shocks reduce agricultural productivity, which means lower agricultural income for farmers, an important source of income, and lower income levels, which, in turn, increase their probability of energy poverty.

3. Materials and methods

3.1. Data

Our research relied on data from the China Family Panel Studies (CFPS), which were conducted by Peking University's Institute of Social Science Survey. The CFPS dataset includes 25 provinces and 162 counties, accounting for 95% of the Chinese population, and offers a nationally representative sample of Chinese households. For this study, we chose four waves of the CFPS survey data in 2012, 2014, 2016, and 2018 to. The CFPS conducts detailed surveys at both household and individual levels. At the household level, one member of the household, generally the household head, completes two questionnaires: one on individual household members' information, such as gender and education, and the other on overall household information, such as member relationships and family spending. This study focused on China's rural regions; hence, the sample was restricted to rural areas. Demographic and socioeconomic data were obtained for all waves. These data allowed us to accurately measure energy poverty in rural households.

The climate data used in this study were obtained from NASA's MERRA2 project (Modern-Era Retrospective Analysis for Research and Applications, Version 2. This global gridded dataset was created by inverting historical weather data from satellite images and weather stations (Hirvonen, 2016). This dataset had a resolution of 1/2° latitude and 2/3° longitude. The MERRA2 dataset is the NASA Global Modeling and Assimilation Office's "Modern Retrospective Analysis for Research and Applications (Version 2)." It was created using a variety of satellite data sources, including OMI, AVHRR, surface observations, GEO atmospheric models, and the GSI analysis framework. It provides long-term, high-quality fundamental data for analyzing regional meteorological conditions (Unfried et al., 2022).

3.2. Energy poverty measurement

Energy poverty can be quantified in several ways. The "objective" technique seeks to capture the link between energy costs and income, while the "subjective" approach is driven by families' perceptions of energy deprivation (Cheng et al., 2021). Objective indicators are more precise than subjective assessments and serve as useful benchmarks for social policy formulation (Charlier & Legendre, 2019). Therefore, numerous experts have quantified energy poverty by using objective indicators. For example, LIHC defines families as energy poor if their energy expenses are more than the median level of energy costs in their province and in a given year (wave), but their residual household income per capita is less than 50% of the province's and year's median household income per capita (Hills, 2012). The following objective indicators are often used to measure energy poverty. For instance, twice the median proportion of whole income (Moore, 2012); 10% measure (Boardman, 1991), showing energy consumption exceeding 10% of family income improved by 10 %. Due to the possibility that the 10% measure overestimates the prevalence of energy poverty by including high-income families, some researchers have used a revised 10% measure that examines only low-income households with incomes of less than the third decile of the household income distribution (Kahouli, 2020).

The mainstream methods for identifying energy poverty are valid. However, this method primarily employs dummy variables to determine whether households are in energy poverty, making it difficult to compare the degree of energy poverty among households. Lin and Zhao (2021) employed the energy expenditure share, an improved 10% indicator, and cleanliness of cooking fuels to jointly construct an energy poverty index that is better for measuring energy poverty in rural Chinese households. The same method was used to create the energy poverty index. Considering that the notion of energy poverty is complicated and multidimensional, we carefully chose a collection of indicators encompassing several dimensions to quantify its many facets and depict energy poverty more accurately. In this study, we created a three-indicator energy poverty index system by adding to the way previous research has measured energy poverty (Lin and Zhao, 2021).

The energy poverty index approach we adopted considers the affordability and accessibility of residential energy services. We used two methods to determine the affordability of energy: a continuous variable energy cost ratio that divides the energy cost by household income, and an improved 10% indicator. Clean cooking was a categorical variable for energy access. It has a value of zero if a family cooks mostly using modern fuels, such as LPG or electricity, and one if it cooks mostly using traditional fuels, such as straw or firewood.

The 10% indicator variable receives a value of one if the household's energy expenses exceed 10% of its total income, according to the indicator's description. Additionally, the improved 10% indicator was utilized to exclude homes with excessive energy usage and high income levels. A composite energy poverty index was generated using the PCA method (principal component analysis) to combine the three variables (Lin and Zhao, 2021). Descriptive statistics and weights for the subindicators of the energy poverty index are shown in Tables A1 and A2, which are provided in Appendix A. The calculated rural household energy poverty index was averaged by county, and its distribution is depicted in Fig. 1.

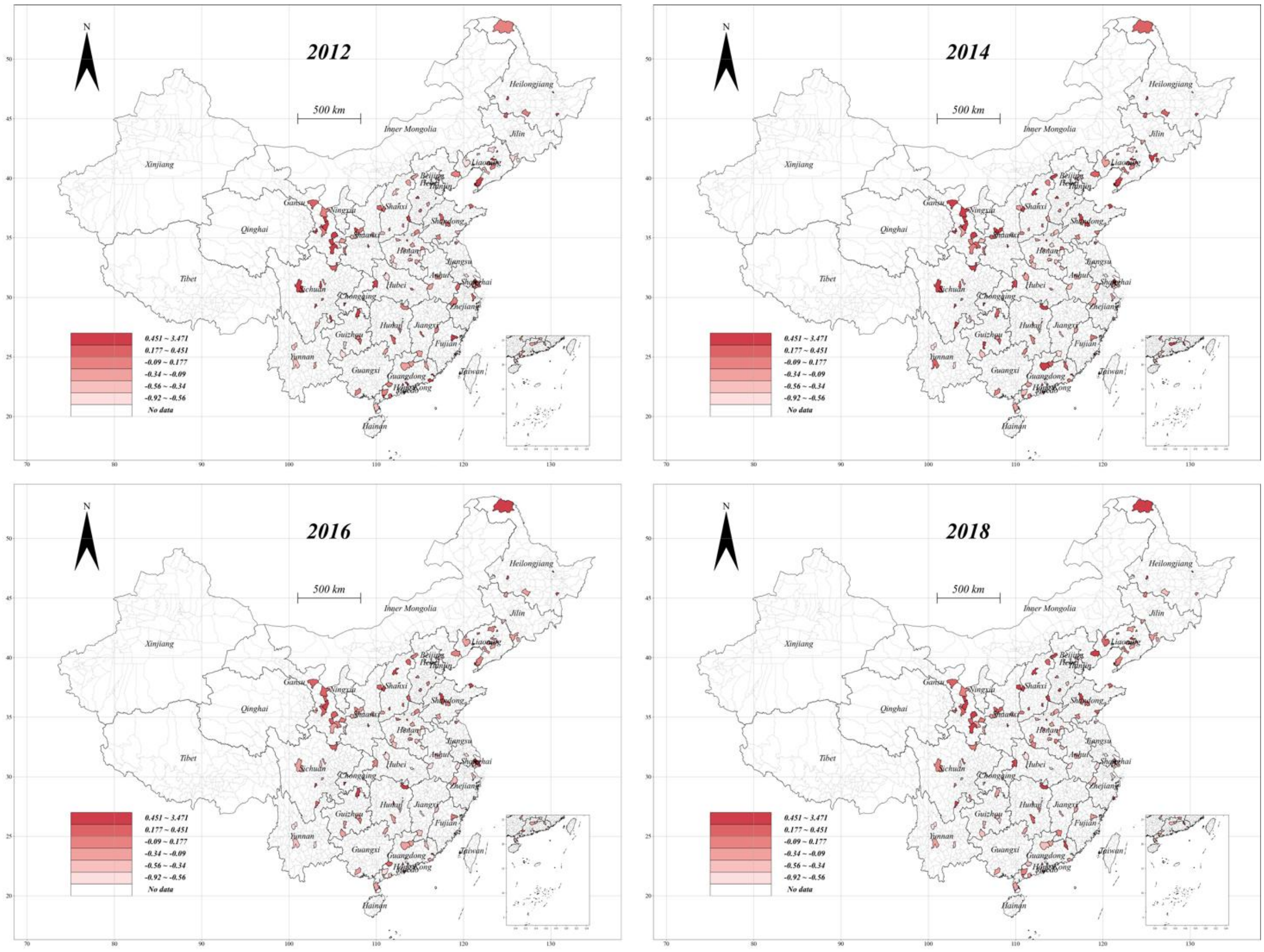

Fig. 1. Spatial distribution of county-level energy poverty index.

3.3. Temperature shocks

Previous studies recommended several temperature-shock methods. In this study, temperature deviations were used to detect shocks. The variances were determined as the difference between the actual temperature and long-term average within a district in a given year divided by the long-term standard deviation for the same district. This method has been frequently used in previous studies (Graff Zivin et al., 2020; Hirvonen, 2016; Letta et al., 2018). Historical temperatures were recorded from 1980 to 2009 prior to our evaluation period. Therefore, our primary measure of a temperature shock is a dummy variable that equals one if the temperature deviates by more than two standard deviations from the long-term average.

We defined our temperature shock variable in this way for various reasons. First, we suggest that level changes are important in proportion to the district's normal volatility rather than in absolute terms. The use of relative values also allows for the deduction of differences owing to different climate types in different regions. Therefore, the temperature bin method was not employed in this study. Second, according to previous research, extreme temperatures cause much stronger responses in energy demand, labor productivity, and crop yield reductions (Awaworyi Churchill et al., 2022; Feeny et al., 2021).

In contrast to previous studies, the wet-bulb temperature was used in this study. The wet bulb temperature is the temperature that considers the effect of the human body's superimposed cooling function. The wet-bulb temperature is the lowest temperature at which air can be cooled by the evaporation of water at a constant pressure. Therefore, it was measured by wrapping a wet wick around the bulb of the thermometer, and the measured temperature corresponded to the wet-bulb temperature. Based on previous research, more than two standard deviations were chosen as thresholds for the occurrence of temperature shocks, and different deviation thresholds were used for robustness tests (Feeny et al., 2021). Fig. 2 depicts the spatiotemporal distribution of temperature shock. Fig. B in Appendix B depicts the temporal trend of the temperature change in the sample area over the last four decades.

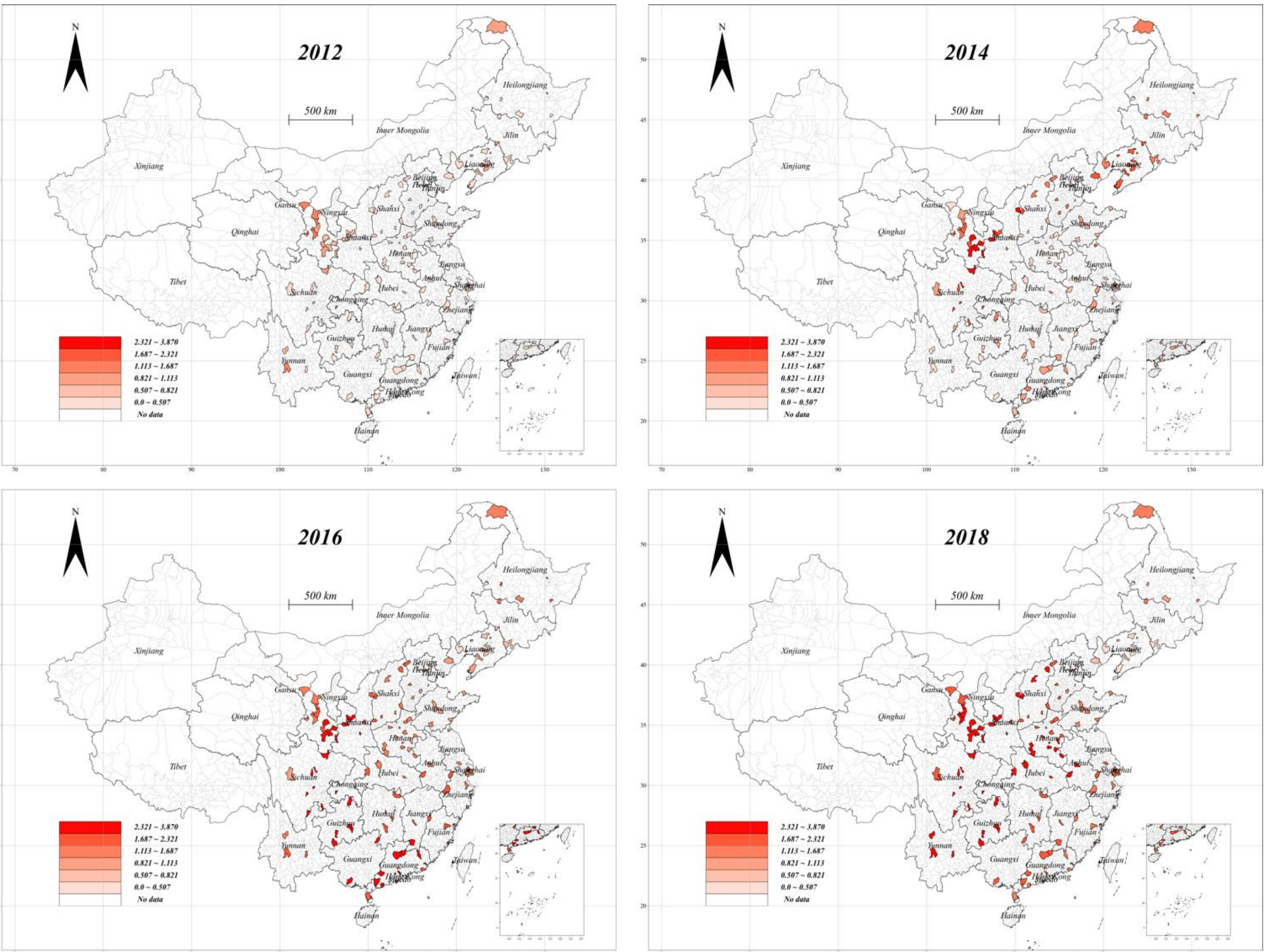

Fig. 2. Spatial distribution of China's county-level temperature shocks.

3.4. Econometric model

This study evaluated the causal effect of temperature shocks on energy poverty. Temperature shock is a quasi-exogenous variable defined as the difference between the present wet-bulb temperature in a household and the historical wet-bulb temperature. The energy poverty index (*EPI*) was the dependent variable, whereas temperature shock (*HS*) was the key independent variable. Descriptive statistics of the variables involved in the econometric model are shown in Table A3. According to Feeny et al. (2021), the econometric model is designed as follows:

$$EPI_{ic,t} = \alpha + \beta_1 HS_{ct} + \beta_2 X_{ic,t} + \mu_p + \delta_t + \mu_p \times \lambda_t + \varepsilon_{ic,t} \tag{1}$$

where $EPI_{ic,t}$ denotes the energy poverty status of household i in county c in year t (2012-2018). HS_{ct} is the key explanatory variable. This study first quantified the disparity between the mean temperature values of the observed variable in county c during year t and long-term mean of the country's temperature spanning the period from 1980 to 2009, with the resulting value normalized by the long-term standard deviation. We ascribe significance to level changes not solely in absolute magnitudes but also in relation to their deviation from the long-term mean. If the difference between the observed temperature and country's long-term mean temperature surpassed a threshold of two standard deviations, a temperature shock was considered to have occurred.

$X_{ic,t}$ is a vector comprising a set of control variables. Our study's control variables consist of household socioeconomic characteristic variables, namely gender of household head, age of household head, education level, marital status, household size, housing ownership, and employment status; the regional control variables consist of energy price, urbanization level, and GDP per capita; and regional climate variables, namely average annual surface temperature, average annual wind speed, average annual precipitation, and average annual humidity. μ_p is the provincial fixed effect, δ_t is the time-fixed effect, and λ_t is the linear temporal trend. By adding provincial fixed effects, we consider time-invariant elements at the provincial level that influence energy poverty, whereas time fixed effects account for any cross-province time trends in energy poverty. To account for provincial-specific macroeconomic trends, the model also included interactions between provincial effects and linear temporal trends. The random disturbance term with an independent and identical distribution is denoted by $\varepsilon_{ic,t}$.

After controlling for the geographical and temporal fixed variables, as well as province-linear time interactions, the fundamental premise of Equation (1) is that temperature shocks were as random as possible. Obviously, there is no assurance that if a temperature shock did not occur, the trends across an impacted province would have followed the same time-series pattern as a non-affected province. The potential bias in the estimation results arises primarily from two factors. First, China has experienced rapid economic growth in recent decades; however, regional disparities exist. Second, the living conditions of rural inhabitants have improved vastly because of the Chinese government's heightened focus on rural development. We attempted to address these problems in two ways. First, this study considers linear time-province fixed effects. Second, our study covers only the years 2012–2018, which is not a very long period.

The short-term impact of temperature shocks on rural household energy poverty during the study period may not capture household adaptation measures because the results of adaptation measures may take some time to capture. Households may adopt adaptive measures to reduce the impact of temperature shocks. Farmers may adjust their planting structures and plant drought-tolerant crops in anticipation of higher temperatures to avoid lower yields. After a temperature shock, it is also possible to compensate for the lost income by working off-farm. Both ex ante avoidance and ex post compensation are adaptive behaviors that can help alleviate energy poverty by compensating for temperature fluctuations. These actions have the potential to prevent families from falling into energy poverty. Equation (2) was used to estimate the following model for the effect, including adaptive behaviors. The long-difference model can be used to estimate adaptive behavioral effects (Burke et al., 2009; Dell et al., 2012). The effects are accounted for in the model, regardless of whether households are aware that the shock is the result of climate change or the adaptive behavior they adopt.

$$EPI_{ic,t} - EPI_{ic,t-1} = \alpha + \beta_{LD} \int_{t-1}^{t} T_{ic,t}\, dt + \gamma_1 (X_{ic,t} - X_{ic,t-1}) + \mu_p + \varepsilon_{it} \tag{2}$$

i represents the household, *c* represents the county, and *t* represents the year. $\int_{t-1}^{t} T_{ci,t} dt$ is a variable between the two periods that reflects the long-term temperature changes, which is defined as the number of days on which the temperature increased above the threshold. X is a control variable, as described above. Provincial fixed effects (μ_p) account for time-invariant elements at the provincial level that influence energy poverty. The random disturbance term with an independent and identical distribution is denoted by ε_{it}. The explanation for β_{LD} is the increase in the number of hot days between the two periods, as well as the cumulative effect. The long-term definition of this study was based on two adjacent studies and the time interval between them due to the small sample size. In this study, the long-term timeframe was set to three years.

4. Empirical results

The results are presented in the following sections. First, we present our main findings before investigating whether heterogeneity exists in the relationship between high-temperature shocks and energy poverty. We find that temperature shocks lead to increased energy poverty. Among all areas, rural households in northern China and remote areas far from provincial capitals were most susceptible to temperature shocks. We then investigated the long-term effects of temperature shocks on energy poverty and the results showed that temperature shocks have long-term effects on energy poverty. For brevity, only the core variables are shown in the results; Appendix B provides the complete results.

4.1. Main results

Table 1 summarizes the results of Equation (1). For clarity, only the findings for the temperature shock variable, which is the main variable of interest, are reported. Table B1 in Appendix B presents the complete results. The findings show that high-temperature shocks have a positive and statistically significant effect on rural households' energy poverty index (Columns 1-3). These results are robust because all three standard deviation threshold settings have a statistically significant effect. The number of hot days has a statistically significant positive effect on the energy poverty index (Columns 4-5). After the threshold was changed, the effects remained consistent and statistically significant.

Table 1

Impacts of temperature shock on energy poverty.

VARIABLES	(1) EPI	(2) EPI	(3) EPI	(4) EPI	(5) EPI
Temperature shock (2 sd)	0.152***				
	(0.0184)				
Temperature shock (2.5 sd)		0.151***			
		(0.0154)			
Temperature shock (3 sd)			0.0466**		
			(0.0186)		
Numbers of hot days (25 ℃)				0.00338***	
				(0.000594)	
Numbers of hot days (22 ℃)					0.00267***
					(0.000771)
Constant	1.324	7.101	-3.090	-9.482	-11.39
	(18.98)	(18.98)	(19.07)	(19.08)	(19.32)
Controls	YES	YES	YES	YES	YES
Province FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Province * linear time	YES	YES	YES	YES	YES
Observations	21,184	21,184	21,184	21,184	21,184
R-squared	0.468	0.469	0.467	0.468	0.467

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

The extent to which the average wet-bulb temperature for a year deviates from its historical value is one of the two types of temperature shocks used in this study. The second method measures the temperature shock by counting the number of days during the year when the wet-bulb temperature exceeds a predetermined threshold. The findings show that both types of high-temperature shock indicators have statistically significant effects on the energy poverty index. This suggests that an increase in both the absolute and relative wet-bulb temperatures worsens energy poverty among rural Chinese households. As discussed in the previous section, high temperatures can directly increase the energy expenditure of rural households and thus lead to energy poverty, which may include the cost of electricity for cooling and the cost of purchasing cooling equipment. Furthermore, high temperatures may deplete human capital and labor productivity, thereby lowering household income. Decreased agricultural production owing to high temperatures can also reduce household income. These are the direct and indirect causes of energy poverty caused by temperature shocks. Although China has now eradicated absolute poverty, rural infrastructure remains deficient, and climate change exacerbates energy poverty, which may jeopardize its progress in the fight against poverty. Our findings suggest that the impact of temperature shocks on energy poverty is a phenomenon that occurs in rural China and should be taken seriously.

4.2. Impact of temperature shocks on energy poverty: Regional heterogeneity analysis

China is a vast country, with significant differences between its northern and southern regions. These differences are primarily reflected in climatic, agricultural production, and rural lifestyle differences. Further analysis of the heterogeneity in China’s northern and southern regions can aid in gaining a better understanding of the impact of temperature shocks on energy poverty. The groupings in the North and South are listed in Table A4.

Table 2 shows the results of the heterogeneity analysis between the northern and southern regions. The results of the northern region analysis (Column 1) show that temperature shocks have a statistically significant positive effect on energy poverty, but only when the standard deviation thresholds are set at 2 and 2.5; when the standard deviation threshold for the occurrence of temperature shocks is set at three standard deviations, the effect of temperature shocks on energy poverty is not significant. The results of the southern region analysis (Column 2) show that temperature shocks have a significant positive effect on energy poverty only when the threshold is set at three standard deviations. The analysis of regional heterogeneity reveals that rural households in the northern region are more vulnerable to temperature shocks than those in the southern region. Rural households in the northern region exhibited energy poverty in response to temperature shocks, with standard deviations of 2 and 2.5. Although the setting at three standard deviations did not show a statistically significant effect of temperature shocks on energy poverty, this was inconsistent with the study's expectations. Our hypothesis is that more intense temperature shocks occur less frequently in northern China; therefore, the estimated results cannot conclude that temperature shocks influence energy poverty. Rural residents in southern China lived in a climate that was more humid and hotter, so they may have coped with high temperatures and thus did not experience a worsening of their energy poverty status at lower levels of temperature shocks. Only intense temperature shocks have an impact on energy poverty. The probability of experiencing a temperature shock in northern China is low; therefore, it is plausible that farmers may not have implemented the requisite precautions. Therefore, they were more vulnerable to temperature shocks. However, as the temperature in northern China has increased significantly over the past several years, and the intensity and duration of temperature shocks will continue to increase in the future. Therefore, mitigating the effects of high temperatures on energy poverty is necessary.

Table 2

Regional heterogeneity analysis (1).

VARIABLES	(1) North EPI	(2) South EPI
Temperature shock (2 sd)	0.164***	-0.00729
	(0.0223)	(0.0396)
R-squared	0.465	0.471
Temperature shock (2.5 sd)	0.200***	0.0233
	(0.0196)	(0.0331)

R-squared	0.467	0.471
Temperature shock (3 sd)	-0.0148	0.0906***
	(0.0247)	(0.0340)
Controls	YES	YES
Province FE	YES	YES
Year FE	YES	YES
Province * linear time	YES	YES
R-squared	0.463	0.471
Observations	13,162	8,022

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Aside from the North-South divide in China, the intra-provincial distribution of rural areas may also introduce variations in the impact of temperature shocks on energy poverty. Rural areas close to cities are also more likely to be more developed. For example, rural areas adjacent to cities benefit from urban development dividends as the cities expand. Science and technology can provide more support to rural areas near cities. Urban residents will have more demand for leisure and vacations, and rural residents will find it more convenient to engage in non-agricultural employment. Therefore, rural areas near cities are more likely to be economically developed and resilient to temperature shocks, resulting in lower levels of energy poverty. Due to the concentration of a province's majority of economic and technological resources in provincial capital cities, which serve as the core cities in provincial economic circles, we employ the proximity of rural areas to provincial capital cities as a proxy variable to determine whether rural areas are adjacent to urban centers. The average distance between the sample county and provincial capital was used as the threshold in this study, and values greater than this were classified as being far away from the provincial capital, that is, remote rural areas.

Table 3 shows the heterogeneity analysis of whether the county is far from the provincial capital city. Under the high-temperature shock with a two standard deviation threshold, both remote areas and adjacent provincial capitals showed a statistically significant increase in the degree of energy poverty. However, the impact was greater in remote rural areas. Only remote rural areas show an increase in energy poverty under more intense temperature shocks (2.5 sd; 3 sd).

Table 3

Regional heterogeneity analysis (2).

VARIABLES	(1) Close to the provincial capital EPI	(2) Away from the provincial capital EPI
Temperature shock (2 sd)	0.0999***	0.183***
	(0.0293)	(0.0427)
R-squared	0.476	0.467
Temperature shock (2.5 sd)	-0.0409	0.188***
	(0.0295)	(0.0259)
R-squared	0.475	0.469
Temperature shock (3 sd)	-0.0393	0.0869***
	(0.0655)	(0.0334)
R-squared	0.475	0.467
Province FE	YES	YES
Year FE	YES	YES
Province * linear time	YES	YES
Observations	10,551	10,633

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

4.3. Impact of temperature shocks on energy poverty: Long-Term Impacts

If there are long-term effects of temperature shocks on energy poverty, not all households will be able to respond to temperature shocks by adopting low-cost adaptation measures such as non-agricultural employment and changing cropping structures. However, the model did not specify household adaptation strategies during this period. If a temperature shock has only a short-term impact on energy poverty and no long-term impact, it would indicate that the temperature shock is less dangerous than it should be. More attention is required if long-term effects occur. For instance, the long-term effects of heat on households may be detrimental to human capital, such as the emergence of health problems, making it difficult for households to recover quickly. There is also an alteration in the household’s production environment, marked by diminished agricultural yields resulting from heat and drought, coupled with amplified production expenses attributed to water scarcity. To counter these challenges, households tend to allocate additional labor to agricultural tasks, such as increased pest control and more frequent irrigation, which diverts time away from more financially lucrative endeavors. Consequently, households face obstacles in augmenting their income and lack opportunities to acquire new skills and techniques to enhance their human capital. Succumbing to these long-term consequences, households risk being ensnared in a perpetual cycle of energy poverty. Therefore, determining whether energy poverty has long-term effects is of crucial practical importance.

Table 4 shows the results of the long-term effects analysis, that is, the Equation (2) estimation results. As the long-difference model necessitated the simultaneous participation of households from two adjacent periods, the sample size was subsequently reduced to 5822. Temperature shocks had a statistically significant and positive effect on energy poverty when different thresholds were replaced. This suggests that households may exhibit adaptive behavior in the long term to reduce the impact of temperature shocks. However, this does not completely eliminate the impact of temperature shocks. Consequently, some households are at risk of becoming trapped in a cycle of energy poverty.

Table 4

Long-Term Impacts of temperature shocks on energy poverty.

	(1)	(2)
VARIABLES	D.EPI	D.EPI
The total number of hot days (25 °C)	0.00288**	
	(0.00116)	
The total number of hot days (22 °C)		0.00276**
		(0.00127)
Constant	173.6**	153.9**
	(73.71)	(74.74)

Province FE	YES	YES
Year FE	YES	YES
Observations	5,822	5,822
R-squared	0.175	0.175

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

5. Conclusions and policy implications

The following are the study's primary findings:

(1) China experienced significant warming in recent years, particularly in the northern regions. There is still a degree of energy poverty in rural China; however, the level of energy poverty is decreasing. Although the rate of energy poverty is relatively high in the western regions, it does not exhibit a distinct overall distribution pattern. This demonstrates that China has made remarkable progress in reducing regional development disparities and achieved balanced development.

(2) The primary conclusion of this study is that temperature shocks exacerbate energy poverty in rural households. It is statistically significant that temperature shocks have a significant and positive effect on energy poverty in rural households. After substituting the various indicators of temperature shocks, the results remained unchanged.

(3) The results of the heterogeneity analysis of the effect of temperature shocks on energy poverty indicate that rural households in the north are more sensitive to temperature shocks than those in the south. Temperature shocks had a greater impact on the energy poverty status of rural households in the northern region than in the southern region. Our study also shows that temperature shocks have a greater impact on the energy poverty status of rural households located far from the provincial capitals.

(4) A long-difference model is used to estimate whether temperature shocks have a long-term impact on energy poverty. Owing to the small sample size, only a three-year time frame could be determined. These results indicate that temperature shocks continue to significantly exacerbate

rural households' energy poverty over time. Despite the long-term impact of temperature shocks being minimal, this indicates that there are still rural households that lack effective adaptation strategies.

The above empirical findings have policy implications. First, future temperature shocks will become increasingly severe due to global warming. This will have multiple effects on the socio-economic system, making it essential that we continue to investigate these effects and accelerate our responses to climate change. The continued existence of energy poverty in rural China cannot be ignored, and accelerating the transition to clean energy and increasing the incomes of rural residents is important.

Second, empirical evidence shows that temperature shocks positively affect energy poverty. The government should convey this information to rural residents along with accurate weather forecasts to help them develop an understanding of how to deal with temperature shocks. Strengthening infrastructure is another important step towards eliminating energy poverty and combating climate change. Enhancing housing infrastructure to make homes less susceptible to heat impacts, ensuring a stable electricity supply by ensuring a stable voltage in remote areas so that residents can use air conditioners effectively. For example, Sichuan Province, China's largest hydroelectric output province, experienced a rare shortage of electricity in 2022 owing to summer heat and drought; therefore, energy supply and climate risk prevention should be strengthened. Provide rural residents with skills and training to increase their income. Increase subsidies for high-temperature electricity use to reduce the likelihood of energy poverty among rural households. All these measures will help China consolidate its progress in eradicating poverty and mitigating the negative effects of temperature shocks.

Third, rural households in northern China are particularly susceptible to temperature shocks, which worsen energy poverty. Simultaneously, the risk of heat waves is exacerbated by the rise in air humidity due to extensive irrigation in northern China (Kang & Eltahir, 2018), which leads to an even greater hazard to energy poverty. Northern China is an essential region for food production and relies heavily on groundwater for irrigation, necessitating a substantial amount of energy for irrigation pumps. Irrigated farmlands increase the likelihood of future heat waves and water shortages resulting from continued heat and drought, threatening the viability of agricultural output. Due to rising temperatures, the likelihood of northern rural households falling into energy poverty is growing. Therefore, the development of water-efficient agriculture to resist climate change adds to the stability of agricultural production, thereby maintaining the agricultural income of rural households and minimizing their risk of energy poverty. However, water-efficient irrigation also helps minimize air humidity and the likelihood of future heat waves in the region. The government should fund this program to simultaneously accomplish these two goals.

Fourth, owing to hot weather, rural households located far from provincial capital cities are more prone to experiencing energy poverty. Rural areas in close proximity to cities are more likely to benefit from urban development, and rural areas in close proximity to cities tend to have better production circumstances, economic growth, and welfare outcomes (Wang et al., 2021). Thus, rural households near cities may better withstand temperature shocks. For instance, rural households in close proximity to the provincial capitals can find non-agricultural jobs more easily. China’s relocation program is considered an efficient policy for eradicating poverty. In distant locations vulnerable to climate change, offering or investing resources to combat climate change may be more difficult because of local physical limitations. In such situations, transferring rural communities from remote places to areas more conducive to their development may be the best method of strengthening their resistance to temperature shocks.

Finally, temperature shocks have lasting effects on energy poverty. Although the impact is small, this indicates that some rural households are unlikely to implement effective temperature-shock adaptation measures. This phenomenon should be taken seriously because it indicates that temperature shocks can trap rural households in a cycle of energy poverty. Damage to human capital such as that caused by temperature shocks may reduce the likelihood of households earning more income over time. Governments should proactively intervene to break the vicious cycle of heat-induced energy poverty in rural households. For instance, enhancing insulated housing for low-income groups can significantly mitigate the adverse effects of temperature shocks. In certain substandard housing conditions, elevated temperatures due to these shocks prevent some farmers from falling asleep until late at night, posing long-term health risks. Hence, there's an urgent need to expand infrastructure support for this demographic to alleviate the impacts of temperature shocks. This becomes imperative for China to sustain its progress in combating poverty effectively.

Appendix A

Table A1
Indicators of Energy Poverty Index.

VarName	Min	Max	Mean	SD
Improved 10% indicator	0.000	1.000	0.277	0.447
Cooking cleanliness	0.000	1.000	0.529	0.499
Percentage of energy expenditure	0.000	0.446	0.088	0.111

Table A2
Energy Poverty Index system.

VarName	Variables	Weights
Affordability	Improved 10% indicator	0.4921
	Percentage of energy expenditure	0.3345
Accessibility	Cooking cleanliness	0.1734

Note: The weights are calculated from PCA.

Table A3
Summary statistics of variables in the econometric model.

Var Name	Description	Mean	SD
EPI	Using a composite index constructed by improved the 10% indicator, household energy expenditure as a percentage of income, and the cleanliness of cooking fuels to measure energy poverty	-0.010	0.928
Temperature shock (2 sd)	=1if the wet bulb temperature exceeds the historical mean by 2 standard deviations	0.520	0.500
Temperature shock (2.5 sd)	=1 if the wet bulb temperature exceeds the historical mean by 2.5 standard deviations	0.297	0.457
Temperature shock (3 sd)	=1 if the wet bulb temperature exceeds the historical mean by 3 standard deviations	0.155	0.362
Numbers of hot days (25 ℃)	The number of days in the year when the average daily wet bulb temperature was above 25 ℃	8.448	20.658
Numbers of hot days (22 ℃)	The number of days in the year when the average daily wet bulb temperature was above 22 ℃	33.206	46.336

Gender	Gender of the head of household	0.615	0.487
Age	Age of head of household	52.407	13.488
Education	=1 indicates education level beyond secondary school	0.256	0.436
Married	=1 indicates that the head of the household is married	0.856	0.352
Household Size	indicates the number of people in the household	4.106	1.934
Home Ownership	=1 indicates that the housing is owned by the head of household	0.942	0.234
Employ	=1 means the head of the household has a work	0.816	0.388
Family income (Log)	Total income of households in the year of the survey	10.310	1.170
Remote areas	=1 indicates far from the provincial capital city	0.502	0.500
Surface Temperature	Average annual surface temperature (°C)	13.317	4.731
Wind Speed	Annual average wind speed at 2 meters above ground (m/s)	1.815	0.645
Precipitation	Average annual precipitation (kg/m^2)	0.049	0.024
Pressure	Annual average sea level pressure (Pa)	101431.312	256.879
Humidity	Annual average specific humidity (kg/kg)	0.008	0.003

Table A4

The specific provinces across different regions.

Region	Provinces
North (15 provinces)	Beijing, Hebei, Tianjin, Inner Mongolia, Shanxi, Jilin, Liaoning, Heilongjiang, Henan, Shandong, Gansu, Shaanxi, Ningxia, Qinghai, Xinjiang
South (15 provinces)	Shanghai, Jiangsu, Hainan, Fujian, Hubei, Jiangxi, Guangxi, Hunan, Guangdong, Sichuan, Guizhou, Chongqing, Zhejiang, Anhui, Yunnan

Appendix B

Supplementary data to this article can be found online.

References

Alkire, S., & Foster, J. (2011). Understandings and misunderstandings of multidimensional poverty measurement. *The Journal of Economic Inequality*, *9*(2), 289–314. https://doi.org/10.1007/s10888-011-9181-4

Aragón, F. M., Oteiza, F., & Rud, J. P. (2021). Climate Change and Agriculture: Subsistence Farmers' Response to Extreme Heat. *American Economic Journal: Economic Policy*, *13*(1), 1–35. https://doi.org/10.1257/pol.20190316

Awaworyi Churchill, S., Smyth, R., & Trinh, T.-A. (2022). Energy poverty, temperature and climate change. *Energy Economics*, *114*, 106306. https://doi.org/10.1016/j.eneco.2022.106306

Bienvenido-Huertas, D., Sánchez-García, D., & Rubio-Bellido, C. (2020). Analysing natural ventilation to reduce the cooling energy consumption and the fuel poverty of social dwellings in coastal zones. *Applied Energy*, *279*, 115845. https://doi.org/10.1016/j.apenergy.2020.115845

Bienvenido-Huertas, D., Sánchez-García, D., Rubio-Bellido, C., & Marín-García, D. (2021). Potential of applying adaptive strategies in buildings to reduce the severity of fuel poverty according to the climate zone and climate change: The case of Andalusia. *Sustainable Cities and Society*, *73*, 103088. https://doi.org/10.1016/j.scs.2021.103088

Boardman, B. (1991). *Fuel Poverty from Cold Homes to Affordable Warmth*.

Burke, M. B., Miguel, E., Satyanath, S., Dykema, J. A., & Lobell, D. B. (2009). Warming increases the risk of civil war in Africa. *Proceedings of the National Academy of Sciences*, *106*(49), 20670–20674. https://doi.org/10.1073/pnas.0907998106

Butler, E. E., & Huybers, P. (2013). Adaptation of US maize to temperature variations. *Nature Climate Change*, *3*(1), 68–72. https://doi.org/10.1038/nclimate1585

Campagnolo, L., & De Cian, E. (2022). Distributional consequences of climate change impacts on residential energy demand across Italian households. *Energy Economics*, *110*, 106020. https://doi.org/10.1016/j.eneco.2022.106020

Carleton, T. A. (2017). Crop-damaging temperatures increase suicide rates in India. *Proceedings of the National Academy of Sciences*, *114*(33), 8746–8751. https://doi.org/10.1073/pnas.1701354114

Chakravarty, S., & Tavoni, M. (2013). Energy poverty alleviation and climate change mitigation: Is there a trade off? *Energy Economics*, *40*, S67–S73. https://doi.org/10.1016/j.eneco.2013.09.022

Charlier, D., & Legendre, B. (2019). A Multidimensional Approach to Measuring Fuel Poverty. *The Energy Journal*, *40*(2). https://doi.org/10.5547/01956574.40.2.bleg

Chen, S., & Gong, B. (2021). Response and adaptation of agriculture to climate change: Evidence from China. *Journal of Development Economics*, *148*, 102557. https://doi.org/10.1016/j.jdeveco.2020.102557

Cheng, Z., Tani, M., & Wang, H. (2021). Energy poverty and entrepreneurship. *Energy Economics*, *102*, 105469. https://doi.org/10.1016/j.eneco.2021.105469

Cole, R., Hajat, S., Murage, P., Heaviside, C., Macintyre, H., Davies, M., & Wilkinson, P. (2023). The contribution of demographic changes to future heat-related health burdens under climate change scenarios. *Environment International*, *173*, 107836. https://doi.org/10.1016/j.envint.2023.107836

Dell, M., Jones, B. F., & Olken, B. A. (2012). Temperature Shocks and Economic Growth: Evidence from the Last Half Century. *American Economic Journal: Macroeconomics*, *4*(3), 66–95. https://doi.org/10.1257/mac.4.3.66

Dell, M., Jones, B. F., & Olken, B. A. (2014). What Do We Learn from the Weather? The New Climate-Economy Literature. *Journal of Economic Literature*, *52*(3), 740–798. https://doi.org/10.1257/jel.52.3.740

Deschênes, O., & Greenstone, M. (2011). Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US. *American Economic Journal: Applied Economics*, *3*(4), 152–185. https://doi.org/10.1257/app.3.4.152

Eichsteller, M., Njagi, T., & Nyukuri, E. (2022). The role of agriculture in poverty escapes in Kenya – Developing a capabilities approach in the context of climate change. *World Development*, *149*, 105705. https://doi.org/10.1016/j.worlddev.2021.105705

Falchetta, G., & Mistry, M. N. (2021). The role of residential air circulation and cooling demand for electrification planning: Implications of climate change in sub-Saharan Africa. *Energy Economics*, *99*, 105307. https://doi.org/10.1016/j.eneco.2021.105307

Feeny, S., Trinh, T.-A., & Zhu, A. (2021). Temperature shocks and energy poverty: Findings from Vietnam. *Energy Economics*, *99*, 105310. https://doi.org/10.1016/j.eneco.2021.105310

Graff Zivin, J., Song, Y., Tang, Q., & Zhang, P. (2020). Temperature and high-stakes cognitive performance: Evidence from the national college entrance examination in China. *Journal of Environmental Economics and Management*, *104*, 102365. https://doi.org/10.1016/j.jeem.2020.102365

Hills, J. (2012). *Getting the Measure of Fuel Poverty: Final Report of the Fuel Poverty Review*. The London School of Economics and Political Science.

Hirvonen, K. (2016). Temperature Changes, Household Consumption, and Internal Migration: Evidence from Tanzania. *American Journal of Agricultural Economics*, *98*(4), 1230–1249. https://doi.org/10.1093/ajae/aaw042

Igawa, M., Piao, X., & Managi, S. (2022). The impact of cooling energy needs on subjective well-being: Evidence from Japan. *Ecological Economics*, *198*, 107464. https://doi.org/10.1016/j.ecolecon.2022.107464

Islam, S., Upadhyay, A. K., Mohanty, S. K., Pedgaonkar, S. P., Maurer, J., & O'Donnell, O. (2022). Use of unclean cooking fuels and visual impairment of older adults in India: A nationally representative population-based study. *Environment International*, *165*, 107302. https://doi.org/10.1016/j.envint.2022.107302

Jurgilevich, A., Käyhkö, J., Räsänen, A., Pörsti, S., Lagström, H., Käyhkö, J., & Juhola, S. (2023). Factors influencing vulnerability to climate change-related health impacts in cities – A conceptual framework. *Environment International*, *173*, 107837. https://doi.org/10.1016/j.envint.2023.107837

Kahouli, S. (2020). An economic approach to the study of the relationship between housing hazards and health: The case of residential fuel poverty in France. *Energy Economics*, *85*, 104592. https://doi.org/10.1016/j.eneco.2019.104592

Kang, S., & Eltahir, E. A. B. (2018). North China Plain threatened by deadly heatwaves due to climate change and irrigation. *Nature Communications*, *9*(1), 2894. https://doi.org/10.1038/s41467-018-05252-y

Kjellstrom, T., Maître, N., & Saget, C. (2019). *Working on A Warming Planet: The Impact of Heat Stress on Labour Productivity And Decent Work*. International Labour Organization.

Letta, M., Montalbano, P., & Tol, R. S. J. (2018). Temperature shocks, short-term growth and poverty thresholds: Evidence from rural Tanzania. *World Development*, *112*, 13–32. https://doi.org/10.1016/j.worlddev.2018.07.013

Li, X. (2012). Hydropower in the Mekong River Basin: A Balancing Test. *Environmental Claims Journal*, *24*(1), 51–69. https://doi.org/10.1080/10406026.2012.663299

Li, X., Chow, K. H., Zhu, Y., & Lin, Y. (2016). Evaluating the impacts of high-temperature outdoor working environments on construction labor productivity in China: A case study of rebar workers. *Building and Environment*, *95*, 42–52. https://doi.org/10.1016/j.buildenv.2015.09.005

Lin, B., & Zhao, H. (2021). Does off-farm work reduce energy poverty? Evidence from rural China. *Sustainable Production and Consumption*, *27*, 1822–1829. https://doi.org/10.1016/j.spc.2021.04.023

Liu, X., Liu, H., Fan, H., Liu, Y., & Ding, G. (2018). Influence of Heat Waves on Daily Hospital Visits for Mental Illness in Jinan, China—A Case-Crossover Study. *International Journal of Environmental Research and Public Health*, *16*(1), 87. https://doi.org/10.3390/ijerph16010087

Lobell, D. B., Bänziger, M., Magorokosho, C., & Vivek, B. (2011). Nonlinear heat effects on African maize as evidenced by historical yield trials. *Nature Climate Change*, *1*(1), 42–45. https://doi.org/10.1038/nclimate1043

Lobell, D. B., Sibley, A., & Ivan Ortiz-Monasterio, J. (2012). Extreme heat effects on wheat senescence in India. *Nature Climate Change*, *2*(3), 186–189. https://doi.org/10.1038/nclimate1356

Maganga, A. M., Chiwaula, L., & Kambewa, P. (2021). Climate induced vulnerability to poverty among smallholder farmers: Evidence from Malawi. *World Development Perspectives*, *21*, 100273. https://doi.org/10.1016/j.wdp.2020.100273

Mashhoodi, B. (2020). Land surface temperature and energy expenditures of households in the Netherlands: Winners and losers. *Urban Climate*, *34*, 100678. https://doi.org/10.1016/j.uclim.2020.100678

Matthews, R., & Wassmann, R. (2003). Modelling the impacts of climate change and methane emission reductions on rice production: A review. *European Journal of Agronomy*, *19*(4), 573–598. https://doi.org/10.1016/S1161-0301(03)00005-4

McDermott, A. (2022). Climate change hastens disease spread across the globe. *Proceedings of the National Academy of Sciences*, *119*(7), e2200481119. https://doi.org/10.1073/pnas.2200481119

McMichael, A. J. (2012). Insights from past millennia into climatic impacts on human health and survival. *Proceedings of the National Academy of Sciences*, *109*(13), 4730–4737. https://doi.org/10.1073/pnas.1120177109

Moore, R. (2012). Definitions of fuel poverty: Implications for policy. *Energy Policy*, *49*, 19–26. https://doi.org/10.1016/j.enpol.2012.01.057

Nguyen, C. P., & Nasir, M. A. (2021). An inquiry into the nexus between energy poverty and income inequality in the light of global evidence. *Energy Economics*, *99*, 105289. https://doi.org/10.1016/j.eneco.2021.105289

Nguyen, C. T., & Scrimgeour, F. (2022). Measuring the impact of climate change on agriculture in Vietnam: A panel Ricardian analysis. *Agricultural Economics*, *53*(1), 37–51. https://doi.org/10.1111/agec.12677

Parry, M. L., Rosenzweig, C., Iglesias, A., Livermore, M., & Fischer, G. (2004). Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change*, *14*(1), 53–67. https://doi.org/10.1016/j.gloenvcha.2003.10.008

Que, N. D., Van Song, N., Thuan, T. D., Van Tien, D., Van Ha, T., Phuong, N. T. M., Huong, N. T. X., & Phuong, P. T. L. (2022). How temperature shocks impact energy poverty in Vietnam: Mediating role of financial development and environmental consideration. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-022-19672-3

Randazzo, T., De Cian, E., & Mistry, M. N. (2020). Air conditioning and electricity expenditure: The role of climate in temperate countries. *Economic Modelling*, *90*, 273–287. https://doi.org/10.1016/j.econmod.2020.05.001

Ravindra, K., Kaur-Sidhu, M., Mor, S., Chakma, J., & Pillarisetti, A. (2021). Impact of the COVID-19 pandemic on clean fuel programmes in India and ensuring sustainability for household energy needs. *Environment International*, *147*, 106335. https://doi.org/10.1016/j.envint.2020.106335

Sadath, A. C., & Acharya, R. H. (2017). Assessing the extent and intensity of energy poverty using Multidimensional Energy Poverty Index: Empirical evidence from households in India. *Energy Policy*, *102*, 540–550. https://doi.org/10.1016/j.enpol.2016.12.056

Saenz, J. L., Adar, S. D., Zhang, Y. S., Wilkens, J., Chattopadhyay, A., Lee, J., & Wong, R. (2021). Household use of polluting cooking fuels and late-life cognitive function: A harmonized analysis of India, Mexico, and China. *Environment International*, *156*, 106722. https://doi.org/10.1016/j.envint.2021.106722

Sanchez-Guevara, C., Núñez Peiró, M., Taylor, J., Mavrogianni, A., & Neila González, J. (2019). Assessing population vulnerability towards summer energy poverty: Case studies of Madrid and London. *Energy and Buildings*, *190*, 132–143. https://doi.org/10.1016/j.enbuild.2019.02.024

Seo, S.-N. N., Mendelsohn, R., & Munasinghe, M. (2005). Climate change and agriculture in Sri Lanka: A Ricardian valuation. *Environment and Development Economics*, *10*(5), 581–596. https://doi.org/10.1017/S1355770X05002044

Sharpe, R. A., Thornton, C. R., Nikolaou, V., & Osborne, N. J. (2015). Fuel poverty increases risk of mould contamination, regardless of adult risk perception & ventilation in social housing properties. *Environment International*, *79*, 115–129. https://doi.org/10.1016/j.envint.2015.03.009

Sheng, Y., Zhao, S., & Yang, S. (2021). Weather shocks, adaptation and agricultural TFP: A cross-region comparison of Australian Broadacre farms. *Energy Economics*, *101*, 105417. https://doi.org/10.1016/j.eneco.2021.105417

Skoufias, E., Rabassa, M., & Olivieri, S. (2011). *The poverty impacts of climate change: A review of the evidence*. The World Bank. https://doi.org/10.1596/1813-9450-5622

Tang, C. F., Tan, B. W., & Ozturk, I. (2016). Energy consumption and economic growth in Vietnam. *Renewable and Sustainable Energy Reviews*, *54*, 1506–1514. https://doi.org/10.1016/j.rser.2015.10.083

Unfried, K., Kis-Katos, K., & Poser, T. (2022). Water scarcity and social conflict. *Journal of Environmental Economics and Management*, *113*, 102633. https://doi.org/10.1016/j.jeem.2022.102633

United Nations. (2021). *The Sustainable Development Goals Report*.

Ürge-Vorsatz, D., & Tirado Herrero, S. (2012). Building synergies between climate change mitigation and energy poverty alleviation. *Energy Policy*, *49*, 83–90. https://doi.org/10.1016/j.enpol.2011.11.093

Wang, Y., Chen, S., & Araral, E. (2021). The mediated effects of urban proximity on collective action in the commons: Theory and evidence from China. *World Development*, *142*, 105444. https://doi.org/10.1016/j.worlddev.2021.105444

Wu, D., Yu, Q., Lu, C., & Hengsdijk, H. (2006). Quantifying production potentials of winter wheat in the North China Plain. *European Journal of Agronomy*, *24*(3), 226–235. https://doi.org/10.1016/j.eja.2005.06.001

Xing, Q., Sun, Z., Tao, Y., Shang, J., Miao, S., Xiao, C., & Zheng, C. (2022). Projections of future temperature-related cardiovascular mortality under climate change, urbanization and population aging in Beijing, China. *Environment International*, *163*, 107231. https://doi.org/10.1016/j.envint.2022.107231

Yang, J. (2018). Climate Change and Domestic Migration in China. *Chinese Journal of Urban and Environmental Studies*, *06*(03), 1850020. https://doi.org/10.1142/S2345748118500203

Yi, W., & Chan, A. (2017). Effects of Heat Stress on Construction Labor Productivity in Hong Kong: A Case Study of Rebar Workers. *International Journal of Environmental Research and Public Health*, *14*(9), 1055. https://doi.org/10.3390/ijerph14091055

Zaveri, E., & B. Lobell, D. (2019). The role of irrigation in changing wheat yields and heat sensitivity in India. *Nature Communications*, *10*(1), 4144. https://doi.org/10.1038/s41467-019-12183-9

Zhao, J., Jiang, Q., Dong, X., & Dong, K. (2021). Assessing energy poverty and its effect on CO2 emissions: The case of China. *Energy Economics*, *97*, 105191. https://doi.org/10.1016/j.eneco.2021.105191

Zhou, L., He, C., Kim, H., Honda, Y., Lee, W., Hashizume, M., Chen, R., & Kan, H. (2022). The burden of heat-related stroke mortality under climate change scenarios in 22 East Asian cities. *Environment International*, *170*, 107602. https://doi.org/10.1016/j.envint.2022.107602

Zivin, J. S. G., Hsiang, S., & Neidell, M. (2015). *Temperature and Human Capital in the Short- and Long-Run* (No. w21157; p. w21157). National Bureau of Economic Research. https://doi.org/10.3386/w21157