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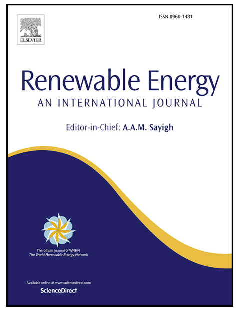

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Jiashun Huang: Conceptualization, Data Curation, Methodology, Writing- Original draft, Reviewing and Editing.

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Lijia Guo: Review & Editing;

Xi Hu: Review & Editing.

Jim Hall: Supervision, Review & Editing.

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Renewable Energy and Household Economy in Rural China

Jiashun Huang[1,2,3], Weiping Li[4, *], Lijia Guo[5, *], Xi Hu[3], Jim W Hall[2]

1. Institute for New Economic Thinking, Oxford Martin School, Oxford OX2 6ED, UK
2. Environmental Change Institute, University of Oxford, Oxford OX1 3QY, UK
3. Labor and Worklife Program, Harvard Law School, Harvard University, Cambridge, MA 02138, USA
4. Department of Economics and Finance, City University of Hong Kong
5. Faculty of Human, Social and Political Science, University of Cambridge, Cambridge CB2 3RQ, UK

Abstract

To understand the linkage between renewable energy and economic growth, this study investigates the development of renewable energy, including hydropower, bioenergy, and solar energy, and their effects on rural household economy, by employing a panel data analysis in China during the period of 2003 - 2017. Based on the evidence of renewable energy infrastructure in the last 20 years, we use a two-way fixed effect model to reveal the relationship between renewable energy investment and household income and consumption. Further, we conduct a panel Granger causality test to verify the impact of renewable energy and economic growth. Empirical results show that investment in renewable energy, including bioenergy, solar energy and hydropower, indeed improve the rural household economy in China.

Keywords: Renewable energy; Household economy; Rural China

* Corresponding authors: W Li, Email: weipingli4-c@my.cityu.edu.hk; L Guo, Email: lg483@cam.ac.uk

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1. Introduction

To reduce the negative effects of environmental pollution and the risks of climate change caused by fossil fuel consumption, it is critical to develop renewable energy replacing conventional energy and make the transition to a clean energy economy. Whilst such a transition will mitigate environmental and human health externalities, the impacts upon the economy are less clear, with some scholars arguing that the economic costs of transition will be high [1, 2], whilst others suggest that the 'green economy' offers employment and growth opportunities [3, 4].

The effects non-renewable energy and renewable energy on economic growth are said to vary significantly [5]. Non-renewable energy resources, such as coal, petroleum, natural gas and nuclear, are available in limited supplies and are bound to be exhausted some time in the future. Renewable resources, such as solar, water (hydro), biomass and wind are replenished naturally. As well as limiting environmental externalities, renewable energy can reduce the energy dependence of one country on others [6].

The economic returns of energy in general has long been investigated in the literature, with most of the focus on fossil fuels. However, the economic impacts of renewable energy have been under-examined and remain controversial. The cost, manufacturing processes and economic benefits of renewable energy are remarkably different from those of conventional fossil energy. There are concerns about the investment requirements for a transition to renewable energy, while the economic

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benefits might be too small [7, 8]. On the other hand, the marginal price of renewable energy can be very low, and the cost of solar and wind technologies is rapidly declining thanks to technological improvement and expanding markets [9, 10].

A particular feature of renewable energy (in particular solar photovoltaic panels and biofuels), distinct from conventional energy, is that it can be installed by households independently. Households are thereby able to utilise solar energy and bioenergy to produce electricity or satisfy other energy needs on their own.

This study intends to examine the economic returns of renewable energy with the following five contributions. First, as the research on the relationship between renewable energy and economic growth has been relatively sparse, this study aims to enrich the literature and furnish evidence on the economic returns of renewable energy. Second, contrary to most the extant literature examining the nexus between energy consumption and GDP, this study focuses on the supply side rather than the demand side, i.e., the deployment and capability of renewable energy, which is more relevant to infrastructure investment and could better advise public policy. Third, unlike most studies looking at large centralised energy systems, this study focuses on renewable energy investment at the household level. These investments are made privately by households, especially in bioenergy and solar energy. Fourth, with a specific research setting in rural areas, which are experiencing a dramatic energy consumption surge yet usually given insufficient attention, this study contributes to our understanding of how rural areas can reach sustainable development outcomes. Fifth, we compose panel data and employ fixed effect models aiming to achieve more robust results. With panel estimation techniques, our research models establish cross-sectional dependence, heterogeneity across the provinces, and Granger causality tests are also applied to investigate the linkage.

Even though renewable energy is now fast developing around the globe, given the large discrepancy among different countries, we narrow the scope of our study on the biggest renewable energy producer country: China. Since the late 1990s, China has been promoting clean, renewable energy, and now has overtaken the US to be the largest renewable producer [11]. Though an enormous number of renewable energy projects have been rolled out, little is known about their actual economic returns. Few studies have tried to address the association between China's renewable energy development and economic growth. This study investigates China's renewable energy with a relatively long time-span, from the earlier period when China started to invest in renewable energy at a large scale around 2003, to the recent year 2017 when it became a renewable energy giant.

The rest of the paper is organised as follows. Section 2 provides a summary of existing literature. Section 3 presents an overview of China's renewable energy. Section 4 is the data and methods. Section 5 is the results. Section 6 discusses its possible physical and economic reasoning. Section 7 concludes.

2. Literature

Research examining the economic returns of non-renewable energy dates back to Kraft and Kraft [12] around four decades ago. They found unidirectional causality running relationship from gross energy inputs to gross national product (GNP) during the period of 1950-1970 in the US. However, Akarca and Long [13] challenged Kraft and Kraft's findings, through a re-examination in which the investigated period was shortened by two years, and found no causal relationships between energy consumption and GNP. Eden and Hwang [14] also lent support to the findings of Akarca and Long, by replicating the tests using updated US data during the period of 1947-1979, and they provided further results revealing no relationship between energy consumption and GNP. The linkage between energy consumption and the economy then became a subject of intense and heated debate around the globe, and subsequently more studies have been conducted in a wide range of countries. For example, there are also a couple of studies looking at developing countries, such as Pakistan [15], Turkey [16], Malawi [17], India [18], and Malaysia [19]. Cross-country studies have also been conducted. Erol and Yu [20] found evidence on the impact of energy consumption on income for West Germany, while no impact for the UK, France and Canada, when employing Sims and Granger causality tests. Glasure and Lee [21] found positive effect of energy consumption on GDP in both South Korea and Singapore when employing cointegration and error-correction models. However, when using the standard Granger causality tests, inconsistent results were found: the results of the standard Granger causality tests indicated no significant economic returns of energy consumption on GDP in South Korea, while causal association were shown in Singapore. Lee [22] re-examined the energy consumption and GDP nexus in 18 developing countries from 1975 to 2001, and after employing the panel

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cointegration and error correction models, the results showed that energy consumption led to economic growth. A general conclusion from the literature is that there is no consensus on the nexus between energy consumption and economic growth [23, 24].

There has been an increasing level of interest in renewables studies from both academics and energy policy analysts. Although renewable energy has a relative short history, there is a growing literature that has looked at its relationship with the economy [25], which is summarised in Table 1.

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Table 1 List of literature on the contribution of renewable energy on economic growth

Economy/Region	Period	Independent variable	Dependent variable	Findings	Methods	Study	Publication
20 OECD countries	1985-2005	Renewable energy consumption	GDP	+	Granger test	[26]	Energy Policy
Turkey	1990-2010	Renewable energy consumption	GDP	-	ARDL approach	[27]	Renewable and Sustainable Energy Reviews
30 OECD countries	1990-2010	Renewable energy consumption	GDP	+	Unit root tests	[28]	Energy Economics
Germany	1971-2013	Renewable energy consumption	GDP	+	Granger test (time series)	[29]	Renewable and Sustainable Energy Reviews
38 countries	1991 -2012	Renewable energy consumption	GDP	+	Panel	[30]	Applied Energy
27 European countries	1997-2007	Renewable energy consumption	GDP	0	Unit root tests (random effect)	[7]	Energy Economics
EU countries	1990-2009	Renewable energy consumption	GDP	+	ARDL approach	[31]	Renewable and Sustainable Energy Reviews
Nine Black Sea and Balkan countries	1990–2012	The share of renewable energy consumption	The rate of GDP growth	+	Unit root tests, FMOLS and DOLS	[32]	Energy Policy
MENA Net Oil Exporting Countries	1980-2012	Renewable electricity consumption	Real GDP	+	Panel cointegration approach	[33]	Energy
US	1994-2006	Renewable electricity consumption	Real GDP	0	Toda-Yamamoto causality test (time series)	[34]	Applied Energy
51 Sub-Sahara African countries	1980–2009	Biomass consumption	GDP	+	Panel	[35]	Applied Energy

Note: + denotes positive effect; - denotes negative effect; 0 denotes no effect

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Most studies use the amount of renewable energy consumption and a country's GDP as the independent variable and dependent variable respectively, but few studies have examined the supply of energy infrastructure, probably owing to a lack of data. Across this work, there is no agreement on the existence of impact of renewable energy development on economic growth [36, 37]. While some have found positive, negligible effects, others argue for negative effects of renewable energy on economic growth. Moreover, most studies use national aggregate data on renewable energy and GDP; few studies have looked at provincial or city level, and even fewer studies have examined the renewable energy-growth nexus in rural areas. Despite the rapid development of China's renewable energy, it is surprising that little has been written. Motivated by the aforementioned controversies and knowledge gaps, this study fills the research lacuna by investigating the deployment of renewable energy and its economic effect in rural China.

3. Renewable Energy in Rural China

3.1 A Dramatic Surge of Energy Consumption in Rural China

Before introducing China's renewable energy in rural areas, it is essential to provide a background of its overall energy consumption, which will help us understand why more research should be focused on rural areas, and the urgency and necessity of renewable energy infrastructure investment and deployment in rural China.

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China once experienced a long period of rural energy shortage, where biomass, such as burning wood and straw, was the only available fuel in these areas. Due to unprecedented economic growth and a profound social change, energy demand in China's rural areas has been rapidly increasing, which has been increasingly supplied from fossil fuel sources. In China's rural areas, energy is now not just demanded for agriculture, but also in all walks of life. China's efforts on promoting national strategical plan for rural vitalisation has now narrowed the urban-rural gap dramatically. As shown in Figure 1, there was a rapid surge in energy consumption in rural China. The rural residential energy consumption per capita was approximately 60 every 1 kg of standard coal (kgce) in 1980, which was less than one-sixth of their urban counterparts (332 kgce). In the early 2000s, however, China's rural residential energy consumption per capita had been soaring (to 390 kgce), and is currently almost equal to urban residential energy consumption per capita (around 395 kgce) in 2016.

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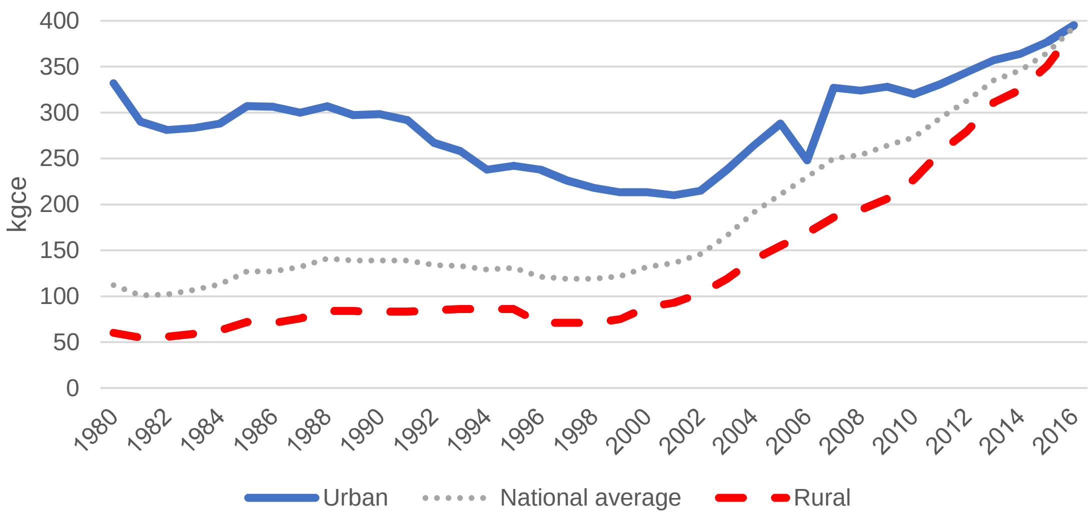

Figure 1 Residential energy consumption per capita, 1980-2016 (*Data source: National Bureau of Statistics of the P.R. of China)*

3.2 Renewable Energy in Rural China

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Driven by policy incentives on energy infrastructure investment to balance growth and environmental concerns and ultimately to reduce the reliance on coal and petroleum, China's rural renewable energy has experienced rapid growth. Rural renewable energy is used in a wide range of daily and productive activities, which not only is necessary for meeting subsistence needs but also forms an integral part of economic production. For instance, in rural areas, solar thermal can provide household hot water, farm machinery with energy supply from hydro plants can be used in harvesting, and bioenergy can provide fuel for cooking food. There are mainly three types of renewable energy in rural China, i.e. hydropower, bioenergy and solar energy.

(i) Hydropower

Hydropower is a mature technology that has been long applied in China's rural areas. It is presently one of the most crucial sources for electricity generation, especially in remote and mountainous areas. Hydropower can provide relatively stable energy supply, in contrast to solar and wind whose supply are intermittent and fluctuating. Therefore, hydropower energy has been widely used in rural China. Although the number of hydropower plants decreased after 1980, the power generating capability was still increasing. There were 47,529 rural hydropower plants, which generated approximately 268 billion kilowatt-hours of electricity (see Figure 2). Once a hydropower plant is operational, it provides pure form of energy, and produces no direct waste. However, it is not easy to build a hydropower plant and the upfront investment costs tend to be high. Moreover, building dams across the river can

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abruptly disturb the natural flow and affect wildlife leading to a series of ecological impacts.

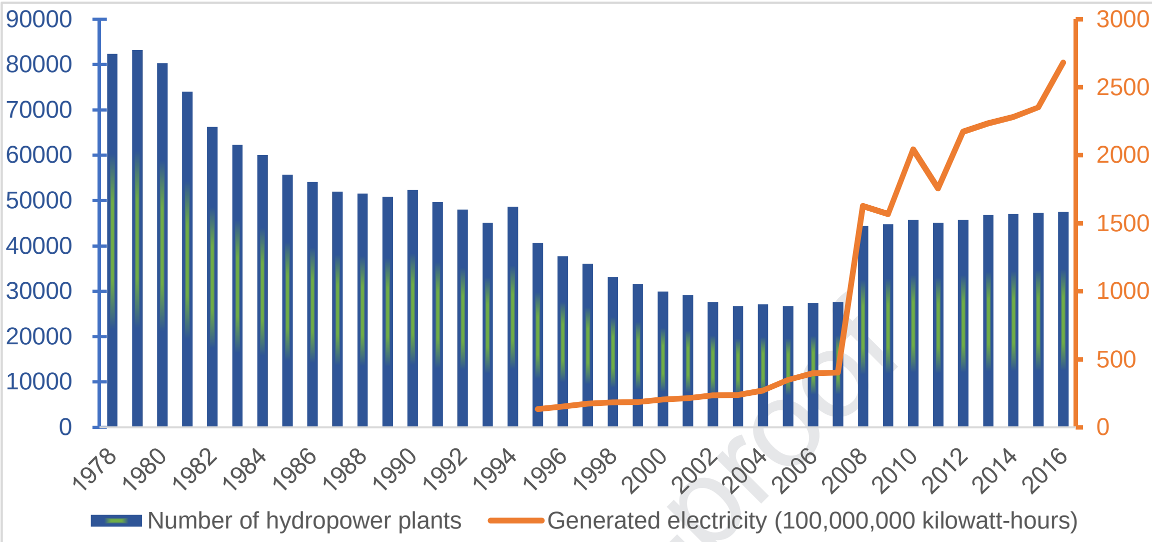

Figure 2 China's hydropower development in rural areas, 1978-2016 *(Data source: Ministry of Water Resources, and National Bureau of Statistics of the P.R. of China)*

(ii) Bioenergy

For a long time, biomass in the form of crop residues, firewood and animal wastes, has been the only available fuel in many rural areas in developing countries. In rural China, biomass was usually used in traditional settings. For example, crop residues were commonly burned in fields, which had low energy efficiency and resulted in air pollution. Since 2000 however, the Chinese government began to implement strict environmental regulations on biomass combustion in rural areas in order to achieve a more sustainable development pathway, whereby a large number of renewable energy infrastructure projects were promoted. China has now built more than 2500 million m^3 of large- and medium-scale biogas projects. The gas production of rural biogas digesters has increased by more than five folds from 2590 million m^3 in the year of 2000 to 1.54 billion m^3 in the year of 2015. Bioenergy can be used for

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multiple purposes, including the production of electricity, heat and fuel, and is beneficial when its waste is converted into things of value. Yet, as we can observe from Figure 3, the development of rural biogas had been stagnating since 2011. This is also consistent with the recent finding of an econometric analysis conducted by Zhang, Wei, Glomsrød and Shi [38], which demonstrated that China's bioenergy consumption fell modestly with income growth. There are several reasons for the resistance of rural bioenergy infrastructure. First, due to China's urbanisation, there is proportionately less rural population and less labour available for collection of biomass, the key materials of biogas production. Second, bioenergy requires substantial transport support, and the transit cost is high, due to the scattered layout of rural biogas digesters. Third, low efficiency of biogas also largely limits its application. Biogas plants tend to experience persistent leakage and seepage problems, and gas production rate is low. Fourth, it is difficult to deal with stockpiles and management of biogas, its raw materials and fertilizer. These obstacles meant that China's rural bioenergy development faced many difficulties, and thus a common and easier way that had been conventionally used is open burning of some biomass, with adverse environmental impacts. To deal with the difficulties in developing bioenergy in rural areas, technology needs to be improved and more effective policies should be implemented to increase the economic value of bioenergy, ensuring that it can be accepted as a clean and low-cost solution for heating and power in rural areas.

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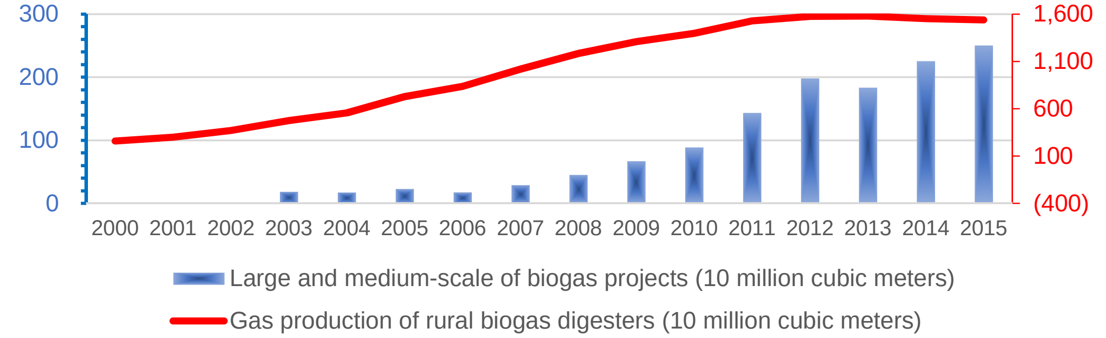

Figure 3 China's bioenergy development in rural areas, 2000-2016 *(Data source: Ministry of Environmental Protection, and National Bureau of Statistics of the P.R. of China)*

(iii) Solar energy

With the boom of solar energy manufacturing, rapid market expansion and technological improvement, the cost of using solar power has dramatically declined [39]. The deployment and use of solar energy has been strongly incentivised by the Chinese government, which has prioritised the utilisation of renewable energy in rural China. Therefore, solar power nowadays is gradually becoming more affordable and commonplace in rural homes. In these areas, millions of households have been using solar cookers and solar water heaters for daily activities. According to Figure 4, the number of solar cookers increased from 0.33 million in 2000 to 2.33 million in 2015. Meanwhile, the number of solar water heaters increased sharply from 11.08 million square meters to 82.33 million square meters in the same 15-year period. The growth of solar energy from 2000 to 2015 has been partially driven by governmental subsidies, tax concessions, and other incentives. Nonetheless, solar energy accounts for just around one percent of China's total energy consumption, and great potential exists for further deployment in rural areas.

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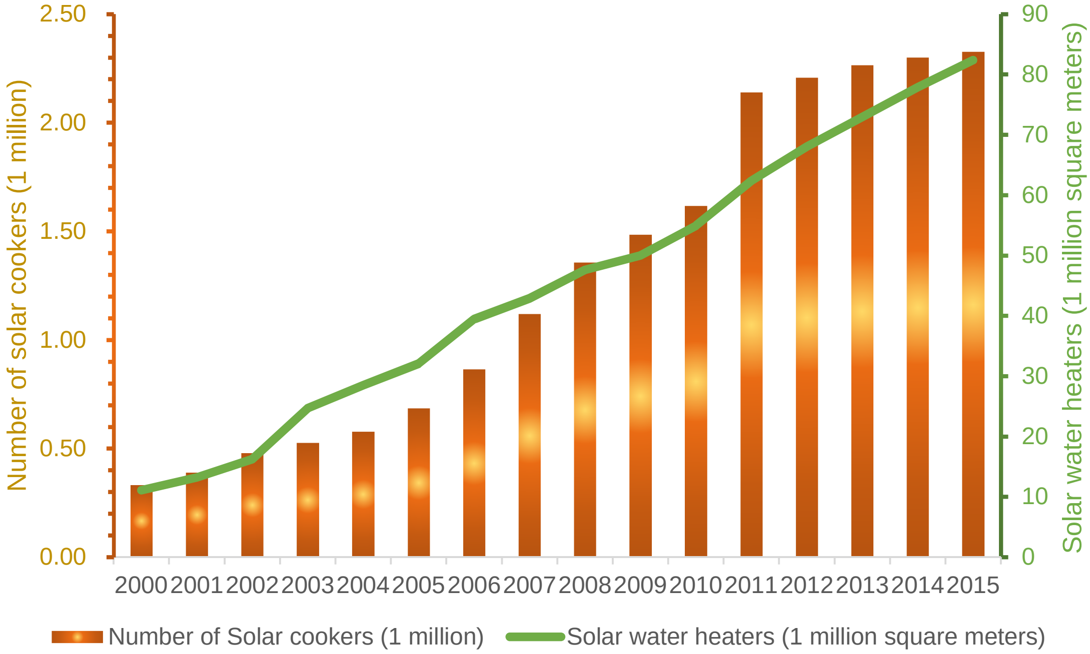

Figure 4 China's solar energy development in rural areas, 2000-2016 (*Data source: Ministry of Environmental Protection, and National Bureau of Statistics of the P.R. of China)*

4. Data and methods

4.1 Data and variables

The data used in this study were collected and complied from multiple sources which are released by several different official institutions, including the National Energy Administration, the Ministry of Water Resources, and the National Bureau of Statistics of the P.R. of China. Data on hydropower were collected from China Water Statistical Yearbook, data on bioenergy and solar energy were collected from China Statistical Yearbook on Environment. Data on total energy consumption were collected from China Energy Statistical Yearbook. Data on rural household economy, including rural household income and household consumption, were collected from China Rural Statistical Yearbook and Rural Areas and Peasantry Database. These data resources are all available to the public. After combining the datasets from different sources, we have been able to compose a panel data for our analysis at the provincial level. These records provide information on China's rural renewable energy, and rural household economy information.

We examine three types of renewable energy sources: hydropower, solar energy and bioenergy. As previously mentioned, in contrast to the most extant studies on consumption, our measures on renewable energy are on the supply side which measures energy deployment and investment. Solar energy is measured by the number of rural solar energy heaters (per 10 thousand square meters), hydropower is measured by the rural hydropower generating capability (per 10 kilo-watt), and bioenergy is measured by the amount of rural gas production by biogas digesters (per 10 million cubic meters). To make the household income comparable among different provinces and periods, we use the growth rate of rural disposable income (per RMB), which is deflated to the price level of year 2000, to measure the household income. Besides, the rural household consumption (per RMB), which is deflated to the price level of year 2000, is employed as the alternative measure to carry out the robust checks. In addition, renewable energy consumption might follow the same trend with the total energy consumption. To alleviate this effect, we include the total energy consumption (10 thousand tons of standard coal) as the control variable. Finally, all the variables are winsorised at 1% level to alleviate the impact of outliers.

We choose the China province-level data from 2003 to 2017 to examine impact of renewable energy and household economy. We begin the sample from 2003 because most of renewable energy data are not available before 2003. Our sample ends by 2017 because the latest available data ends by 2017. For statistical purposes, the data analysis mainly includes the provinces in mainland China, and the Hong Kong SAR, Macau SAR and Taiwan Province of China are not included because these areas have significant difference in the economic system with the mainland China. Besides, Tibet and Shanghai are excluded because some key variables are missing. Finally, we acquire a sample of 29 provinces and 435 province-year observations.

4.2 Methodology

The function for household economy and the impact of different types of renewable energy is shown in Equation 1.

$$Economy_{i,t} = f(Hydropower_{i,t},\ Bioenergy_{i,t}, Solar\ energy_{i,t},\ Total\ Energy_{i,t}) \quad (1)$$

We employ the log-linear function to measure the effect of renewable energy. To alleviate the effect of unobservable effect of the region and time, we include the provincial fixed effect and year fixed effect in the model, as shown in Equation 2.

$$lnEconomy_{i,t} = \alpha + \beta_1 lnHydropower_{i.t} + \beta_2 lnBioenergy_{i.t} + \beta_3 lnSolar\ engergy_{i.t} +$$

$$\sum Province_i + \sum Year_t + \varepsilon_{i.t} \quad (2)$$

where i denotes the id of a province, and t=2003, …, 2017 denotes the time period. $Economy_{i,t}$ denotes the dependent variable, rural household economy[1]. ε denotes the error term. The summary statistics and correlation matrix are listed in Table A1 and

[1] Because economy is the growth rate and range from -1 to +1, we take the natural logarithm of economy plus one.

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Table A2 in the appendixes.

In terms of econometrical methods, a large proportion of literature used time series data and techniques. For example, Tang, Tan and Ozturk [37] used annual time series data on conventional energy consumption and GDP of Vietnam in the neoclassical Solow growth framework. Arora and Shi [36] investigated the linkage between conventional energy consumption and GDP in the US using a multivariate time varying model. Pao and Fu [40] used yearly statistics in Brazil to compare the relationship between renewable energy, non-renewable energy and GDP by employing vector error correction models. However, given the defects of time series data, panel data have several advantages which better uncover the dynamic relationships, and there have been increasingly longitudinal studies on exploring the relationship in energy economics. For instance, both Saad and Taleb [41] and Alper and Oguz [31] used panel analysis to explore the impact of renewable energy on GDP in European countries.

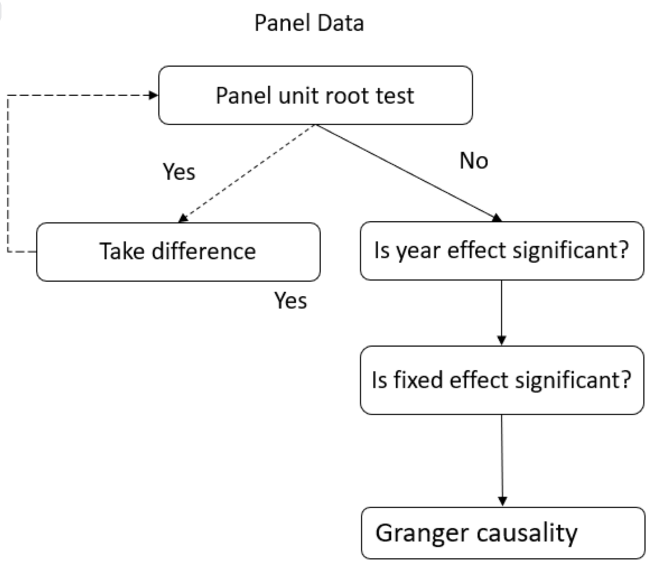

Figure 4 Empirical strategy flowchart

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To examine the relationship between renewable energy and household economy in rural areas, we employ longitudinal data at province level in China to conduct a series of tests. First, we carry out the panel unit root test to examine whether the data are stationary, and the results show that all the variables are stationary. Next, we examine whether the time effect if significant to choose whether to include year fixed effects. We further investigate whether the province fixed effect matters in our regressions. Both tests show that year and province level fixed effects are significant. Thus, we use two-way fixed effect panel models to control for the province level fixed effect and year fixed effect. Such models could control for unobserved heterogeneity when the heterogeneity is invariant over time. This heterogeneity can be removed from the data. However, fixed effect models cannot tackle the problems of group-wise heteroskedasticity and cross-sectional independence. Thus, we adjust the standard errors by clustering at the province level and year level to alleviate the impact of heteroskedasticity.

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Lastly, in line with existing literature [42], we use the Granger causality test to examine the nexus between renewable energy and the economy. This study implements a recent technique with procedures proposed by Dumitrescu and Hurlin [43] (DH), to detect the Granger causality in panel datasets.

In the Granger causality test, we suppose the independent variables ($x_{i,t,}$) and the dependent variable ($Economy_{i,t}$) are two variables for province i in period t. The relationship between $x_{i,t}$ and $Economy_{i,t}$ is expressed as Equation 3.

$$Economy_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_{i,k}\, Economy_{i,t-k} + \sum_{k=1}^{K} \beta_{i,k}\, x_{i,t-k} + \varepsilon_{i,t}$$

(3)

The regression coefficients are different among different provinces but time-invariant. The lag order K is supposed to be the same for all provinces and there must be a balanced panel. DH test assumes that causality exists in some provinces but not necessarily for all provinces. Thus, the null hypothesis and alternative hypothesis are expressed as Equation 4 and 5:

$$H_0: \beta_{i1} = \cdots = \beta_{iK} = 0 \qquad \forall\, \mathrm{i} = 1, \dots, \mathrm{N} \tag{4}$$

$$H_1: \beta_{i1} = \cdots = \beta_{iK} = 0 \qquad \forall\, \mathrm{i} = 1, \dots, \mathrm{N}_1$$

$$\beta_{i1} \neq 0 \;\; or \;\; \cdots or = \beta_{iK} \neq 0 \qquad \forall\, \mathrm{i} = \mathrm{N}_1 + 1, \dots, \mathrm{N} \tag{5}$$

In Equation 4, $\mathrm{N}_1 \in [0, \mathrm{N} - 1]$ is unknown. If $\mathrm{N}_1 = 0$, all provinces have causalities in the panel. N must be larger than N_1, otherwise no province has causality and H_1 would be same with H_0.

We run the regression in Equation 3 at first and then conduct the F-tests for hypothesis 1 to acquire the Wald statistic W_i for each province and compute the final Wald statistic $\overline{\mathrm{W}}$(W-bar) by averaging all the W_i, shown in Equation 6.

$$\overline{\mathrm{W}} = \frac{1}{N} \sum_{i=1}^{N} W_i \tag{6}$$

In the DH test, W_i is assumed to be independent and identically distributed across provinces, and can be expressed as the standardized statistic $\overline{\mathrm{Z}}$ when $\mathrm{T} \rightarrow \infty$ first and then $\mathrm{N} \rightarrow \infty$, which follows a standard normal distribution in Equation 7:

$$\overline{\mathrm{Z}} = \sqrt{\frac{N}{2K}} (\overline{\mathrm{W}} - K) \xrightarrow{T, N \rightarrow \infty} N(0,1) \tag{7}$$

Using this technique, we are able to compute the p-values and critical values related to the Z-bar ($\overline{\mathrm{Z}}$) via a bootstrap procedure, which is beneficial in the case of cross-sectional dependence [44].

5 Results

5.1 Main results

First, we conduct the panel unit root test to check whether all the variables are stationary. Next, we carry out F test to examine whether the year and province fixed effect model should be incorporated in the model. These results are shown in Table A4 in the appendixes. All the p values are smaller than 0.01, indicating that fixed effect model is more effective than random effect model.

In Table 2, we regress the rural household economy variable with the hydropower, bioenergy and solar energy variables in models 1-3 separately. Then, we include all the variables in model 4. The values of R-squared are higher than 0.3, indicating that renewable energy has high explanatory power for the household economy. The coefficients of hydropower are positive and significant at the 5% level in both model 1 and model 4, indicating that hydro electricity production promotes the household economy. Bioenergy also has significantly positive coefficients in both model 2 and model 4, illustrating that it has positive effects on the household economy of rural areas. Finally, the coefficients of solar energy in model 3 and model 4 are significant and positive, demonstrating that the development of solar energy promotes household economy.

Table 2 Results of fixed effect panel regression

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VARIABLES	(1) model1 lnGrowth2	(2) model2 lnGrowth2	(3) model3 lnGrowth2	(4) model4 lnGrowth2
Bioenergy	0.011**			0.011**
	(0.004)			(0.004)
Hydropower		0.008*		0.008*
		(0.004)		(0.005)
Solar Energy			0.004*	0.004***
			(0.002)	(0.001)
Energy	-0.002	-0.002	0.000	-0.011
	(0.036)	(0.036)	(0.039)	(0.034)
Constant	-0.071	-0.063	-0.007	-0.107
	(0.340)	(0.352)	(0.354)	(0.348)
Observations	435	435	435	435
Adjusted R-squared	0.335	0.330	0.329	0.336
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes

Standard errors are adjusted by clustering at both province and year level, and are reported in parentheses;
*** p<0.01, ** p<0.05, * p<0.1

To further verify the relationship between renewable energy and the household economy, we employ the xtgcause command in Stata to conduct the Granger casual test and the results are shown in Table 3. The p values of Z-bar are smaller than 0.05, rejecting the null hypothesis that they are not Granger-cause. Hence, hydropower, bioenergy and solar energy have the Granger causal effects on rural household economic growth.

Table 3 Result of the Granger casual test

	W-bar	Lag	Z-bar	Z-bar p
Hydropower	5.670	3	5.870	0.000
Bioenergy	4.435	3	3.156	0.002
Solar energy	6.911	3	8.599	0.000

Based on the Granger tests in Table 3, and the results of fixed effect regression in Table 2, we can roughly estimate that: One standard deviation (SD) increase in rural

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solar energy heater increases rural household economy by 11.7%(0.004*1.504/0.051) SD of economic growth; one SD increase in rural biogas (biogas digesters) increases rural household economy by about 36.45% (0.008*2.324/0.051) SD of economic growth. Besides, one SD hydropower improvement would contribute to 32.89% SD of economic growth. Thus, the renewable energy has substantial effect on economic growth of China rural areas.

5.2 Robust checks- alternative measure for household economy

We employ the amount of total household disposable consumption in the rural area (economy2) to replace the original measure on household economy expenditure per capital. The results are presented in Tables A5 in the appendix and we find that the results are consistent with our prior findings, further verifying our results

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6. Discussion

Based on the results, we find evidence that the development of new renewable energy, including bioenergy, solar energy and hydropower, is positively and significantly associated with the rural household economy. Why does the deployment of renewable energy contribute to the rural household economy? In this section, we attempt to discuss several possible economic mechanisms. First, investment in renewable energy facilities usually require external funding, and China’s central and local governments have been providing substantial financial incentives in rural areas, including subsidies, tax-related incentives, loans, and pricing incentives, which also influence saving rates or debt servicing in rural household economy. For example, during 2003- 2009, it was estimated that the Chinese governments had provided 19 billion RMB as financial investment and incentives for the biogas industry. Among them, 82% was invested in household biogas digesters, which significantly stimulated bioenergy infrastructure development [45]. However, the government would usually just provide strong incentives at the early stage of an emerging industry, and then the development of renewable energy would be mainly driven by the market. The manufacture, construction and installation of these energy facilities will impact demand for various economic sectors and employment. Where greater renewable energy deployment exists, rural households tend to get more employment [46]. Moreover, with persistent governmental encouragement and support in rural renewable energy development, larger scale manufacturing and deployment of renewable energy facilities reduce the marginal cost, which also contributes to higher economic returns [47]. In addition, higher renewable energy investment may activate a sense of entitlement because government and individuals perceive a higher importance of new technology and innovation, which contributes to a more sustainable business environment and phase out outdated, low-efficiency and low-output technology [48]. This transition could further contribute to rural household economy. Last, with renewable energy, rural households will gradually replace the use of conventional energy with higher marginal costs, which may save the cost of daily energy consumption and reduce the living expense burden for households [49]. Surplus renewable energy can be sold, which creates profits for rural households.

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Other processes could also explain the results. Future research is necessary to establish which of these, or other, mechanisms explain why higher renewable energy deployment could have positive economic returns.

7. Conclusion

This study has added new evidence to energy-economy nexus literature, from the supply side, at household level and a rural perspective on renewable energy. Based on evidence of a largescale longitudinal panel spanning 15 years, the results of this empirical study show that renewable energy in rural China is beneficial for economic growth. Specifically, the development of renewable energy, in the form of bioenergy, solar energy and hydropower, both promote China's rural economy. This study estimates that one standard deviation increase in rural solar thermal energy, in rural biogas and in hydropower, would contribute to an increase of 11.7%, 36.45% and 32.89% of rural household economy, respectively. Our findings imply that improvement in renewable energy deployment could increase the household economic wealth in rural areas.

Appendixes

Table A1 shows the descriptive statistics of the renewable energy variables and rural household economy variables in our sample. Table A2 shows the correlations between our variables. Table A3 presents the results of panel unit root test. Table A4 shows the fixed effect test results. Table A5 demonstrates the robustness tests of the results when we use the amount of total household consumption in the rural area (economy2) as an alternative measure.

Table A1 Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Economy	435	0.011	0.051	-0.123	0.136
Economy2	435	0.021	0.056	-0.113	0.200
Hydropower	435	9.775	1.525	5.669	12.288
Bioenergy	435	11.836	2.324	6.131	15.221
Solar energy	435	4.432	1.504	-0.357	7.020
Total energy	435	9.176	0.740	6.963	10.522

Table A2 Correlation matrix

	Economy	Economy2	Hydropower	Bioenergy	Solar energy
Economy	1				
Economy2	0.575***	1			
Hydropower	0.015	-0.011	1		
Bioenergy	0.092*	0.039	0.544***	1	
Solar energy	-0.062	-0.065	0.451***	-0.085*	1
Total energy	-0.069	-0.06	0.413***	0.05	0.456***

*** p<0.01, ** p<0.05, * p<0.1

Table A3 Results of Panel Unit Root test

	Levin-Lin-Chu test		
	Unadjusted T	Adjusted T	p value
Economy	-15.430	-7.425	0.000
Hydropower	-23.495	-21.922	0.000
Bioenergy	-10.044	-7.581	0.000
Solar energy	-12.057	-8.860	0.000

Table A4 Results of fixed effect test

	Year effect		Province effect	
	F	p value	F	p value
Model 1	14.107	0.000	1.715	0.014
Model 2	14.382	0.000	1.422	0.078
Model 3	14.579	0.000	1.625	0.025
Model 4	13.994	0.000	1.627	0.025

Table A 5 Results of fixed effect panel regression (alternative measure)

	(1)	(2)	(3)	(4)
	Model 1	Model 2	Model 3	Model 4
VARIABLES	Economy2	Economy2	Economy2	Economy2

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Bioenergy	0.014*			0.014*
	(0.007)			(0.007)
Hydropower		0.012*		0.012*
		(0.006)		(0.006)
Solar Energy			0.007***	0.007***
			(0.001)	(0.001)
Energy	-0.022	-0.023	-0.021	-0.036
	(0.032)	(0.027)	(0.033)	(0.027)
Constant	0.091	0.093	0.180	0.039
	(0.290)	(0.319)	(0.305)	(0.322)
Observations	435	435	435	435
Adjusted R-squared	0.330	0.325	0.324	0.337
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes

Standard errors are adjusted by clustering at both province and year level, and are reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1

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References

[1] W.D. Nordhaus, To slow or not to slow: the economics of the greenhouse effect, The Economic Journal 101(407) (1991) 920-937.

[2] W.D. Nordhaus, Revisiting the social cost of carbon, Proceedings of the National Academy of Sciences 114(7) (2017) 1518-1523.

[3] O. Mehmet, Employment creation and green development strategy, Ecological Economics 15(1) (1995) 11-19.

[4] A. Markandya, I. Arto, M. González-Eguino, M.V. Román, Towards a green energy economy? Tracking the employment effects of low-carbon technologies in the European Union, Applied Energy

179 (2016) 1342-1350.

[5] S. Shafiei, R.A. Salim, Non-renewable and renewable energy consumption and CO2 emissions in OECD countries: A comparative analysis, Energy Policy 66 (2014) 547-556.

[6] M. Pacesila, S.G. Burcea, S.E. Colesca, Analysis of renewable energies in European Union, Renewable and Sustainable Energy Reviews 56 (2016) 156-170.

[7] A.N. Menegaki, Growth and renewable energy in Europe: a random effect model with evidence for neutrality hypothesis, Energy Economics 33(2) (2011) 257-263.

[8] A. Bergmann, N. Hanley, R. Wright, Valuing the attributes of renewable energy investments, Energy Policy 34(9) (2006) 1004-1014.

[9] C. Andini, R. Cabral, J.E. Santos, The macroeconomic impact of renewable electricity power generation projects, Renewable Energy 131 (2019) 1047-1059.

[10] D. Connolly, H. Lund, B.V. Mathiesen, E. Pican, M. Leahy, The technical and economic implications of integrating fluctuating renewable energy using energy storage, Renewable Energy 43 (2012) 47-60.

[11] J. Helveston, J. Nahm, China's key role in scaling low-carbon energy technologies, Science 366(6467) (2019) 794-796.

[12] J. Kraft, A. Kraft, On the relationship between energy and GNP, The Journal of Energy and Development (1978) 401-403.

[13] A.T. Akarca, T.V. Long, On the relationship between energy and GNP: a reexamination, The Journal of Energy and Development (1980) 326-331.

[14] S. Eden, B.-K. Hwang, The relationship between energy and GNP: further results, Energy Economics 6(3) (1984) 186-190.

[15] A. Aqeel, M.S. Butt, The relationship between energy consumption and economic growth in Pakistan, Asia-Pacific Development Journal 8(2) (2001) 101-110.

[16] G. Altinay, E. Karagol, Structural break, unit root, and the causality between energy consumption and GDP in Turkey, Energy Economics 26(6) (2004) 985-994.

[17] C.B. Jumbe, Cointegration and causality between electricity consumption and GDP: empirical evidence from Malawi, Energy Economics 26(1) (2004) 61-68.

[18] S. Paul, R.N. Bhattacharya, Causality between energy consumption and economic growth in India: a note on conflicting results, Energy Economics 26(6) (2004) 977-983.

[19] J.B. Ang, Economic development, pollutant emissions and energy consumption in Malaysia, Journal of Policy Modeling 30(2) (2008) 271-278.

[20] U. Erol, E.S. Yu, On the causal relationship between energy and income for industrialized countries, The Journal of Energy and Development (1987) 113-122.

[21] Y.U. Glasure, A.-R. Lee, Cointegration, error-correction, and the relationship between GDP and energy:: The case of South Korea and Singapore, Resource and Energy Economics 20(1) (1998) 17-25.

[22] C.-C. Lee, Energy consumption and GDP in developing countries: a cointegrated panel analysis, Energy economics 27(3) (2005) 415-427.

[23] I. Ozturk, A literature survey on energy–growth nexus, Energy Policy 38(1) (2010) 340-349.

[24] R.J. Elliott, P. Sun, Q. Xu, Energy distribution and economic growth: An empirical test for China, Energy Economics 48 (2015) 24-31.

[25] W. Saad, A. Taleb, The causal relationship between renewable energy consumption and economic growth: evidence from Europe, Clean Technologies and Environmental Policy (2018) 1-10.

[26] N. Apergis, J.E. Payne, Renewable energy consumption and economic growth: evidence from a

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panel of OECD countries, Energy Policy 38(1) (2010) 656-660.

[27] O. Ocal, A. Aslan, Renewable energy consumption–economic growth nexus in Turkey, Renewable and Sustainable Energy Reviews 28 (2013) 494-499.

[28] R. Inglesi-Lotz, The impact of renewable energy consumption to economic growth: A panel data application, Energy Economics 53 (2016) 58-63.

[29] A.A. Rafindadi, I. Ozturk, Impacts of renewable energy consumption on the German economic growth: Evidence from combined cointegration test, Renewable and Sustainable Energy Reviews 75 (2017) 1130-1141.

[30] M. Bhattacharya, S.R. Paramati, I. Ozturk, S. Bhattacharya, The effect of renewable energy consumption on economic growth: Evidence from top 38 countries, Applied Energy 162 (2016) 733-741.

[31] A. Alper, O. Oguz, The role of renewable energy consumption in economic growth: Evidence from asymmetric causality, Renewable and Sustainable Energy Reviews 60 (2016) 953-959.

[32] E. Koçak, A. Şarkgüneşi, The renewable energy and economic growth nexus in Black Sea and Balkan countries, Energy Policy 100 (2017) 51-57.

[33] M. Kahia, M.S.B. Aïssa, L. Charfeddine, Impact of renewable and non-renewable energy consumption on economic growth: New evidence from the MENA Net Oil Exporting Countries (NOECs), Energy 116 (2016) 102-115.

[34] J.E. Payne, On the dynamics of energy consumption and output in the US, Applied Energy 86(4) (2009) 575-577.

[35] I. Ozturk, F. Bilgili, Economic growth and biomass consumption nexus: Dynamic panel analysis for Sub-Sahara African countries, Applied Energy 137 (2015) 110-116.

[36] V. Arora, S. Shi, Energy consumption and economic growth in the United States, Applied Economics 48(39) (2016) 3763-3773.

[37] C.F. Tang, B.W. Tan, I. Ozturk, Energy consumption and economic growth in Vietnam, Renewable and Sustainable Energy Reviews 54 (2016) 1506-1514.

[38] R. Zhang, T. Wei, S. Glomsrød, Q. Shi, Bioenergy consumption in rural China: Evidence from a survey in three provinces, Energy Policy 75 (2014) 136-145.

[39] Z.-y. Zhao, S.-Y. Zhang, B. Hubbard, X. Yao, The emergence of the solar photovoltaic power industry in China, Renewable and Sustainable Energy Reviews 21 (2013) 229-236.

[40] H.-T. Pao, H.-C. Fu, Renewable energy, non-renewable energy and economic growth in Brazil, Renewable and Sustainable Energy Reviews 25 (2013) 381-392.

[41] W. Saad, A. Taleb, The causal relationship between renewable energy consumption and economic growth: evidence from Europe, Clean Technologies and Environmental Policy 20(1) (2018) 127-136.

[42] M. Ahmed, M. Azam, Causal nexus between energy consumption and economic growth for high, middle and low income countries using frequency domain analysis, Renewable and Sustainable Energy Reviews 60 (2016) 653-678.

[43] E.-I. Dumitrescu, C. Hurlin, Testing for Granger non-causality in heterogeneous panels, Economic Modelling 29(4) (2012) 1450-1460.

[44] L. Lopez, S. Weber, Testing for Granger causality in panel data, The Stata Journal 17(4) (2018) 972-984.

[45] C. Wang, Y. Zhang, L. Zhang, M. Pang, Alternative policies to subsidize rural household biogas digesters, Energy Policy 93 (2016) 187-195.

[46] U. Lehr, J. Nitsch, M. Kratzat, C. Lutz, D. Edler, Renewable energy and employment in Germany,

Journal Pre-proof

Energy Policy 36(1) (2008) 108-117.
[47] U. Pillai, J. McLaughlin, A model of competition in the solar panel industry, Energy Economics 40 (2013) 32-39.
[48] H. Liu, D. Liang, A review of clean energy innovation and technology transfer in China, Renewable and Sustainable Energy Reviews 18 (2013) 486-498.
[49] L. Gan, J. Yu, Bioenergy transition in rural China: Policy options and co-benefits, Energy Policy 36(2) (2008) 531-540.

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Highlights:

- The effect of renewable energy on rural economic growth in China is explored
- Based on the evidence in the last 14 years, we find effect of renewable energy on rural economy
- Rural economics performs better in areas with high renewable energy usage
- Reasons that deployment of renewable energy contributes to the rural household economy is explored

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Declaration of interests

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

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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