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ADB Working Paper Series

**ENVIRONMENTAL CHALLENGES
AND SUSTAINABLE ECONOMIC
DEVELOPMENT IN THE PEOPLE'S
REPUBLIC OF CHINA: THE ROLE
OF RENEWABLE ENERGY ACROSS
PROVINCES**

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Abstract

In recent times, the People's Republic of China (PRC) has faced significant challenges in terms of managing its environment and moving forward with the concept of sustainable economic development. The environmental challenges concern the increasing consumption of fossil fuel energy, which has caused a substantial rise in carbon emissions. As a result, in 2015, the PRC alone contributed about 28% of the global carbon dioxide (CO₂) emissions, while it contributed 17% of the global GDP. Against this backdrop, this study aims to explore empirically the impact of renewable (hydro) energy use on the economic output and carbon emissions using annual data on 28 provinces of the PRC. For this reason, the study takes yearly data from 2000 to 2014 and applies a battery of recently developed panel econometric techniques. The empirical results of augmented mean group estimations show that renewable energy has an insignificant impact on the output in all the panels. Further, the results indicate that renewable energy has a negative impact on carbon emissions in the full sample and in coastal and western provinces, but again it is insignificant. However, it contributes positively to carbon emissions in central provinces. This evidence therefore suggests that the level of renewable energy consumption has not reached a level at which it will have significant positive and negative impacts on the output and emissions, respectively.

Keywords: renewable energy, carbon emissions, economic output, urbanization, People's Republic of China

JEL Classification: O44, Q42, Q48, Q56

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1. INTRODUCTION

Global warming and climate change have become important environmental challenges for the world in recent decades. Not only has the academic literature discussed these issues extensively, but also they have become the hot topics among the popular media, political commentaries, and non-government and non-profit organizations (Rafiq, Salim, and Nielsen 2016). Researchers' consider the accumulation of carbon dioxide (CO₂) and other greenhouse gas (GHG) emissions as a main cause of environmental issues (Nordhaus 1991). The People's Republic of China (PRC) has been experiencing rapid growth in terms of energy use and emissions since 2000. According to the International Energy Agency, the PRC has been the highest energy consumer in the world since 2009. During the period 2000–17, the annual average GDP growth rate was around 9%, the energy consumption grew by more than 19%, and the annual CO₂ emissions increased sharply by more than 200%. The developing countries, with faster economic growth and more energy consumption, receive constant criticism for their disproportionate contribution to climate change. Among the emerging and newly industrialized countries, the PRC's overdependence on coal has already made it the highest CO₂ emitter in the world. To mitigate air pollution and improve the environment, the PRC government set up a major air quality plan—the *Three-Year Plan of Action for Winning the War to Protect Blue Skies*—in 2018. Renewable energy is a good choice as a substitute for fossil fuels, which cause severe global warming and climate change. From 2000 to 2017, the share of renewable energy in electricity production in the PRC gradually increased from 16% to 26%.

The large CO₂ emissions and the rise of energy consumption in the PRC have attracted a considerable amount of attention from scholars in energy economics. Several research scholars have examined the impact of energy consumption on economic outcomes (e.g., Bloch, Rafiq, and Salim 2015; Shahbaz, Khan, and Tahir 2013; Wang et al. 2011; Yuan et al. 2008; Zhang and Cheng 2009). These studies reported mixed findings on the nexus between energy use, CO₂ emissions, and economic outcomes. Despite the accumulated knowledge on energy consumption, economic growth, and environmental degradation in the PRC, few studies have explored the effects of renewable energy use on both growth and emissions in the PRC in a single study. Moreover, most of the existing studies have only focused on a single level (national, regional, or city) of analysis rather than conducting a comprehensive investigation including multiple levels.

Given that background, we explore the effect of renewable (hydro) energy use on the economic output and carbon emissions using annual data on 28 provinces of the PRC from 2000 to 2014. The sample of our study includes 28 provinces with 15 observations for each province. We divide these provinces into three groups—coastal, central, and western areas. We estimate our proposed relationship between renewable energy consumption, economic growth, and environmental degradation for the three regions. This research paper makes use of an environmental theoretical model, specifically STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology), and the neo-classical growth model to explore empirically the effects of the use of renewable energy (hydro) on emissions and economic output. For the empirical investigation, we use several robust and recently developed panel econometric techniques. More specifically, we employ a panel unit root test, which relies on the assumption of cross-sectional dependence, to explore the order of integration of the selected variables. We also examine empirically the augmented mean group (AMG) estimator based on the cross-sectional dependence to explore the effect of renewable energy and urbanization on the economic output and carbon emissions across the panels. Finally, this study also makes use of fixed-effect and

unconditional quantile regression methods to determine the economic output and emissions across the panels of the PRC provinces.

We make the following three contributions to the literature. First, to our knowledge, this is the first study to investigate comprehensively the consequences of renewable energy use from the perspectives of both environmental degradation and economic output in the PRC. As a typical example of the emerging and newly industrialized economies, the policy makers in the PRC need to take environmental problems and the economic output into consideration simultaneously and strike a balance between these two outcomes. One of the remedial solutions that tend toward sustained development is the promotion of renewable energy generation and use. Second, we study the effects of renewable energy consumption at the levels of provinces and regions. In this way, we can gain insights into not only the differences among provinces but also the similar pattern of relationships within each region and the differences between the coastal, central, and western regions. Finally, this is also the first effort to investigate the relationship among the considerable number of variables across the full sample and regions using the AMG and unconditional quantile regression methods. Given these findings and arguments, we believe that our study makes a significant contribution to the policy and practical knowledge on the effects of renewable energy use on the environment and economic growth in the PRC.

We structure the paper as follows. Section 2 discusses the relevant literature on the theories and the empirical findings of urbanization and energy consumption; Section 3 describes the nature of the data and selected provinces and regions and provides details of the models and empirical methodology; Section 4 reports the estimated findings and their detailed policy and practical implications; and Section 5 provides the concluding remarks of the paper.

2. LITERATURE REVIEW

According to Stern (2007), global warming may reduce the global GDP by up to 25%; the cost of reducing the greenhouse gas emissions would be 1% of the global GDP. Many people have realized that, without a strong action of greenhouse gas emission control, our earth could be heading toward a great economic recession (DeCanio 2009; Menyah and Wolde-Rufael 2010; Reddy and Assenza 2009; Stern 2007). People consider renewable energy (hydro, wind, solar, and geothermal) to be a substitute for fossil fuels. Many scholars believe that, as a clean, carbon-free form of energy, renewable energy is the primary solution to global warming (Ferguson 2007). While some papers have explored the causal association between energy consumption, CO₂ emissions, and economic growth (Dinda 2004; Ozturk 2010), to our knowledge, our paper is the first to investigate the impact of renewable energy on economic growth and CO₂ emissions across the PRC provinces.

The panel study by Masih and Masih (1996) used a dynamic vector error-correction technique and found a positive causal nexus between energy consumption and economic growth in six Asian developed and developing economies. Sharma (2011) used a sample of 69 countries from 1985 to 2005 and showed a positive effect of per capita energy consumption on emissions and a negative effect of urbanization on CO₂ emissions. When dividing the 69 economies into three groups (based on income levels), energy consumption has a positive effect on CO₂ emissions, while urbanization has the opposite impact in all three income groups.

Zhang and Cheng (2009) focused on the PRC as a single country and found unidirectional causality that runs from energy use to CO₂ emissions from 1960 to 2007.

By utilizing an ARDL test to examine the long-run and short-run relationships, in a comparative study between the PRC and India, the fastest growing economies, Jayanthakumaran, Verma, and Liu (2012) showed that energy consumption results in more CO₂ emissions in both countries.

At the regional level, Herrerias, Joyeux, and Girardin (2013) used the panel cointegration method to exhibit unidirectional causality from economic growth to energy use in the long term during the period 1999–2009. Xu and Lin (2015) explored the impact of urbanization on emissions from 1990 to 2011 and showed that there is an inverted U-shaped connection between urbanization and CO₂ emissions in the eastern region, a positive U-shape in the central region, and no association in the western region.

At the province or city level, Dhakal (2009) analyzed 661 cities in the PRC in 2004 and showed that urbanization contributes to energy consumption and CO₂ emissions, with the 35 biggest cities contributing 40% of energy use and CO₂ emissions; Fei et al. (2011) documented a long-run cointegrated association between energy consumption and economic growth in 30 provinces of the PRC during the period 1985–2007; and Wang et al. (2014) discovered a bidirectional positive association between energy consumption, urbanization, and CO₂ emissions and reported that the magnitude of association depends on the economies of scale of the respective provinces. Using data from 28 provinces during the period 1995–2007, Wang et al. (2016) demonstrated a bidirectional relationship between CO₂ emissions and energy consumption as well as energy consumption and economic growth. Focusing on Beijing as a specific example, Feng, Chen, and Zhang (2013) used the STELLA platform to model its trends of energy consumption and CO₂ emissions over the period 2005–2030. Their modeling results showed that, as the energy structure changes from carbon-rich fuel to low-carbon fuel, the CO₂ emissions in Beijing will decrease in the long run.

In summary, the existing empirical studies have mainly considered only one antecedent, energy consumption, and captured only one outcome, either environmental problems or economic growth. In addition, most of these studies have been conducted at a single level, and the causality between variables is ambiguous. Against this backdrop, our study aims to explore the effects of renewable (hydro) energy use on emissions and economic output at the provincial and regional levels in the PRC. For this reason, the study makes use of a battery of recently developed panel econometric techniques. Hence, the results obtained from this study will add considerable insights for policy and practice.

3. DATA AND METHODOLOGY

3.1 Data

Our dataset is an annual balanced panel at the provincial level from 2000 to 2014. We collected data from 28 provinces in the PRC, namely Anhui, Beijing, Chongqing, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hainan, Hebei, Heilongjiang, Henan, Hubei, Hunan, Inner Mongolia, Jiangsu, Jiangxi, Jilin, Liaoning, Ningxia, Qinghai, Shaanxi, Shandong, Shanxi, Sichuan, Tianjin, Xinjiang, Yunnan, and Zhejiang (note that we did not include Shanghai, Tianjin, and Tibet Autonomous Region because of the data availability and quality of these regions).

The main objective of this paper is to examine the effect of renewable (hydro) energy use on the economic output and carbon emissions for a panel of 28 provinces in the PRC. We first conduct a panel data analysis using the full sample of 28 provinces. More

specifically, we apply a robust panel regression technique, namely the augmented mean group (AMG) estimator, which Eberhardt and Bond (2009) and Eberhardt and Teal (2010) developed. Then, to investigate further whether the nexus between renewable (hydro) energy use, economic output, and carbon emissions among the geographically different regions in the PRC are substantially different, we classify the 28 provinces into three regions: (i) the coastal area (Beijing, Hebei, Liaoning, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi, and Hainan); (ii) the central area (Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan); and (iii) the western area (Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang). We then apply the fixed-effect regression method, unconditional quantile regression, which is based on the approach of Firpo, Fortin, and Lemieux (2009), to evaluate the effect of renewable energy use on the economy and emissions from the perspective of quantiles.

We obtained the data required for this paper from each year's *China Statistical Yearbook* and the provincial statistical yearbooks from 2000 to 2014.¹ The measurements of the variables are as follows: we use hydroelectricity output (HYPO) to represent the renewable energy use and measure it in billion kilowatt hours; the gross domestic product (Output) of each province/municipality is a measure of economic output; and we use capital formation (CAP) to describe the net capital accumulation during the selected accounting period for each province/municipality. We express both the economic output and the net capital accumulation in 100 million yuan. The per capita CO₂ emissions (CDE) are in metric tons; labor is the total labor force (LBF) in 10,000 persons; the population (POP) is measured in 10,000 persons; the per capita income (PI) measures the average income earned per person in yuan; and the degree of urbanization (URBN) is the percentage of the total population living in urban areas.

3.2 Model Setting

This paper aims to explore the impact of renewable energy use on CO₂ emissions and economic growth across 28 provinces and three regions in the PRC. For this reason, we utilize annual data, from 2000 to 2014, and apply a battery of panel econometric techniques, including the AMG estimator, fixed-effect regression, and unconditional quantile regression, respectively.

The presence of cross-sectional dependence (CSD) in the panels may affect the validity of the tests that rely on the assumption of CSD independence (Moscone and Tosetti 2009). To account for possible CSD in our data, we employ Pesaran's (2004) CD test to examine each series to confirm whether there is CSD. Moreover, stationarity is an important assumption for a well-fitting econometric model. Thus, we make use of Pesaran's (2007) CIPS unit root test, which accounts for CSD and examines the order of integration of each of the variables in the model. The null hypothesis for the CIPS test is a unit root and again no unit root for the alternative hypothesis.

¹ The data availability determines the selection of the sample period.

If we detect the presence of cross-sectional dependence among the panel units, estimation models with homogeneous slope coefficients may lead to distortions in the standard panel estimators (Eberhardt and Bond 2009). Hence, to account for CSD, we use the AMG estimator to treat residual cross-sectional dependence, heterogeneous slopes, and non-stationary residuals across provinces. We can specify our panel data model as follows:

$$OUTPUT_{it} = f(CAP_{it}, LBF_{it}, HYPO_{it}, URBN_{it}) \quad (1)$$

$$CDE_{it} = f(POP_{it}, PI_{it}, HYPO_{it}, URBN_{it}) \quad (2)$$

where *OUTPUT*, *CAP*, *LBF*, *HYPO*, *URBN*, *CDE*, *POP*, and *PI* stand for the economic output, capital, labor force, hydroelectricity output, urbanization, CO₂ emissions, population, and per capita income, respectively. Meanwhile, $t = 1, 2, \dots, T$, and $i = 1, 2, \dots, N$ represent the time period and cross-section (provinces), respectively.

To determine whether our results hold for all the quantiles, we employ the unconditional quantile regression of Firpo, Fortin, and Lemieux (2009). We can use their model directly to examine the economic impact of a change in the explanatory variables on the corresponding quantiles of the unconditional distribution of an outcome variable, which is usually of real interest in economic applications.²

4. RESULTS AND DISCUSSION

We begin our analysis by attempting to estimate the unconditional correlations among the selected variables of the study. Table 1 displays the unconditional correlations. The correlation results show that the output is positively correlated with renewable energy (HYPO) and urbanization across the panels of the study. Further, the correlation of output with renewable energy and urbanization is much stronger in western and central provinces than in coastal provinces. The results also suggest that carbon emissions are negatively correlated with renewable energy in coastal provinces, while the relationship is positive in both central and western provinces. Finally, the results imply that the per capita income is positively associated with the economic output and carbon emissions across the panels. Overall, these results establish considerable associations among the variables.

A number of recent studies have argued that panel data-based studies must take CSD into account in their investigation; otherwise, the estimated results may be spurious and may produce a misleading interpretation of the findings. Hence, in this study, we first examine our panel data to determine whether they have cross-sectional dependence or independence. For this purpose, we apply the CD test, which Pesaran (2004) developed. Table 2 presents the results of the CD test. The results strongly reject the null hypothesis of CD independence, which basically confirms that the variables considered in the panels of the full sample and the coastal, central, and western provinces have cross-sectional dependence. Given these results, we therefore make sure that we apply the econometric methods in this paper that address the issue of CSD in the analysis; otherwise, the findings may be spurious.

² We avoid a detailed discussion of the econometric techniques to conserve space in the paper.

Table 1: Estimates of Unconditional Correlations on Panel Data Sets

	OUTPUT	CDE	CAP	LBF	POP	PI	HYPO	URBN
Full sample								
OUTPUT	1.000							
CDE	0.836	1.000						
CAP	0.976	0.834	1.000					
LBF	0.574	0.574	0.475	1.000				
POP	0.728	0.722	0.623	0.840	1.000			
PI	0.734	0.502	0.804	0.003	0.069	1.000		
HYPO	0.010	-0.039	0.035	0.020	0.072	-0.057	1.000	
URBN	0.517	0.256	0.529	-0.093	-0.068	0.820	-0.206	1.000
Coastal								
OUTPUT	1.000							
CDE	0.880	1.000						
CAP	0.988	0.883	1.000					
LBF	0.623	0.719	0.585	1.000				
POP	0.791	0.883	0.752	0.814	1.000			
PI	0.698	0.395	0.724	0.059	0.115	1.000		
HYPO	0.093	-0.050	0.070	-0.125	-0.021	0.176	1.000	
URBN	0.334	0.011	0.309	-0.151	-0.174	0.746	0.231	1.000
Central								
OUTPUT	1.000							
CDE	0.709	1.000						
CAP	0.981	0.715	1.000					
LBF	0.515	0.348	0.418	1.000				
POP	0.444	0.350	0.340	0.983	1.000			
PI	0.846	0.578	0.887	-0.012	-0.102	1.000		
HYPO	0.392	0.048	0.382	0.318	0.242	0.291	1.000	
URBN	0.361	0.183	0.413	-0.505	-0.573	0.742	0.132	1.000
Western								
OUTPUT	1.000							
CDE	0.875	1.000						
CAP	0.971	0.856	1.000					
LBF	0.465	0.419	0.314	1.000				
POP	0.709	0.616	0.546	0.794	1.000			
PI	0.628	0.554	0.767	-0.220	-0.104	1.000		
HYPO	0.432	0.226	0.373	0.401	0.533	0.020	1.000	
URBN	0.384	0.358	0.536	-0.366	-0.307	0.879	-0.299	1.000

Note: We estimated the unconditional correlations using "natural log" data.

Table 2: Cross-Sectional Dependence (CD) Test Results

Variable	Full Sample		Coastal		Central		Western	
	CD test	p-value	CD test	p-value	CD test	p-value	CD test	p-value
OUTPUT	75.060a	0.000	23.140a	0.000	23.170a	0.000	25.920a	0.000
CDE	71.040a	0.000	21.580a	0.000	22.510a	0.000	24.530a	0.000
CAP	74.390a	0.000	22.970a	0.000	23.020a	0.000	25.610a	0.000
LBF	35.770a	0.000	14.640a	0.000	19.160a	0.000	2.690a	0.007
POP	32.510a	0.000	22.960a	0.000	5.560a	0.000	5.160a	0.000
PI	75.000a	0.000	23.110a	0.000	23.160a	0.000	25.920a	0.000
HYPO	48.010a	0.000	9.820a	0.000	15.870a	0.000	21.970a	0.000
URBN	72.480a	0.000	22.270a	0.000	22.400a	0.000	25.150a	0.000

Notes: The CD test follows Pesaran's (2004) methodology; "a" indicates the rejection of the null hypothesis of cross-sectional independence at the 1% significance level.

Given the evidence of CSD across the panels, we apply the CIPS test, which Pesaran (2007) proposed and developed. Table 3 presents the results of the CIPS test. The results on level data across the panels reveal that the null hypothesis is accepted. This evidence suggests that all the selected variables have the unit root in the level data. Further, we apply the CIPS test to the first-difference data, and the results establish the rejection of the null hypothesis. Hence, our CIPS test results establish that the selected variables are integrated of order I (1).³

Table 3: Panel Unit Root Test (CIPS) Results on Level Data

Variable	Full Sample		Coastal		Central		Western	
	Zt-bar	p-value	Zt-bar	p-value	Zt-bar	p-value	Zt-bar	p-value
OUTPUT	2.880	0.998	2.558	0.995	0.537	0.704	1.849	0.968
CDE	0.204	0.581	-0.159	0.437	0.344	0.634	1.652	0.951
CAP	-0.201	0.420	0.011	0.504	0.991	0.839	2.501	0.994
LBF	2.779	0.997	4.341	1.000	0.725	0.766	1.110	0.866
POP	2.923	0.998	0.358	0.640	0.397	0.654	0.150	0.560
PI	2.342	0.990	2.028	0.979	0.415	0.661	1.732	0.958
HYPO	-0.525	0.300	-0.859	0.195	-0.020	0.492	0.658	0.745
URBN	2.076	0.981	-1.159	0.123	-1.468	0.071	1.543	0.939

Notes: We estimate the CIPS test using the methodology of Pesaran (2007); the test incorporates the trend variable; and the above results imply that none of the variables reject the null hypothesis of a unit root, under cross-sectional dependence, at the 5% level of significance.

Given the results of the CD and CIPS tests, we employ the AMG estimator to investigate empirically the effect of renewable energy and urbanization on the economic output and carbon emissions across the panels of the full sample and the coastal, central, and western provinces. In the analysis, we also account for important control variables. More specifically, in the output model, we account for the capital and labor variables, while, in the carbon emission model, we account for the population and per capita income. To build the growth model, we use the revised version of the neo-classical growth theory, whereas we construct the carbon emission model

³ We do not report the CIPS test results on first-difference data series in the paper. However, the findings confirm stationarity at the first difference for all of the selected variables in the study.

following the approach that the STIRPAT model suggests. Hence, we build both our output and our carbon emission model by making use of the theoretical approaches.

The results of the AMG estimators are presented in Table 4. The empirical findings from the AMG estimate show that the effect of renewable energy on the economic output is statistically insignificant but that its effect on carbon emissions is significant and positive only in central provinces. Instead, renewable energy appears to be having a negative but statistically insignificant effect on carbon emissions in coastal and western provinces. Likewise, urbanization drives the economic output and carbon emissions across the panels, but again it is statistically insignificant. Given this evidence, we argue that the consumption of renewable energy has not reached a level at which it will have a significant positive impact on economic growth and negative impact on carbon emissions across the PRC provinces.

Table 4: Augmented Mean Group (AMG) Estimations

	Full Sample		Coastal		Central		Western	
	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.
<i>OUTPUT = f (CAP, LBF, HYPO, URBN)</i>								
CAP	0.154a	0.001	0.235a	0.003	0.089c	0.057	0.134a	0.006
LBF	0.526	0.168	0.682a	0.002	-0.295	0.372	0.196	0.572
HYPO	0.002	0.817	-0.005	0.695	0.001	0.954	-0.005	0.817
URBN	0.262	0.233	0.395	0.283	0.134	0.726	0.286	0.208
Trend	-0.019b	0.033	-0.038a	0.004	-0.004	0.766	-0.011	0.383
Constant	1.405	0.664	-0.109	0.966	9.327a	0.000	3.439	0.180
<i>CDF = f (POP, PI, HYPO, URBN)</i>								
POP	-0.185	0.972	3.471	0.584	-4.600c	0.054	-3.041	0.830
PI	0.288	0.110	-0.296	0.539	0.493b	0.017	0.316	0.153
HYPO	-0.049	0.253	-0.081	0.138	0.047a	0.001	-0.048	0.657
URBN	0.283	0.869	-3.088	0.461	0.308	0.788	2.975	0.339
Trend	0.070	0.206	0.084	0.628	0.006	0.722	0.123c	0.082
Constant	-1.017	0.978	-4.947	0.933	42.617b	0.023	-1.090	0.991

Notes: The AMG method is based on the approach that Eberhardt and Bond (2009) and Eberhardt and Teal (2010) suggested; this method accounts for cross-sectional dependence and allows for heterogeneous slope coefficients across panel members; the trend variable accounts for panel-specific linear trends; "a," "b," and "c" indicate the 1%, 5%, and 10% significance levels, respectively.

For the purpose of robustness checks, we again apply the fixed-effect and unconditional quantile regression methods to investigate the role of renewable energy in the economic output and carbon emissions across these panels of provinces. Table 5 reports the results of the fixed-effect models. The results reveal that a rise in renewable energy fosters economic development in the full sample and the central provinces, and these parameters are statistically significant at the 1% level. The results also imply that the impact on economic growth from renewable energy is positive in coastal and western provinces but statistically insignificant. Similarly, the impacts from capital, labor, and urbanization on the economic output are positive and statistically significant. Further, our results establish that an increase in renewable energy has a negative effect on emissions in western provinces, whereas its effect in other provinces is insignificant. The growth of urbanization contributes positively to environmental degradation in all the provinces with the exception of coastal provinces, where it is insignificant.

Table 5: Regression Results with Fixed Effects

Variable	Full Sample		Coastal		Central		Western	
	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.
<i>OUTPUT = f (CAP, LBF, HYPO, URBN)</i>								
Constant	1.223a	0.000	1.029a	0.004	-1.713	0.272	1.168a	0.007
CAP	0.733a	0.000	0.824a	0.000	0.639a	0.000	0.702a	0.000
LBF	0.005	0.561	0.008	0.592	0.389c	0.069	0.000	0.973
HYPO	0.027a	0.006	0.009	0.414	0.087a	0.001	0.036	0.273
URBN	0.381a	0.000	0.288b	0.011	0.513a	0.000	0.398b	0.024
<i>CDF = f (POP, PI, HYPO, URBN)</i>								
Constant	-2.455	0.392	14.12 a	0.000	18.515a	0.000	-40.948a	0.000
POP	0.569	0.106	-1.561a	0.001	-1.761a	0.000	5.355a	0.000
PI	0.542a	0.000	0.804a	0.000	0.506a	0.000	0.625a	0.000
HYPO	0.026	0.336	-0.001	0.957	0.033	0.234	-0.262b	0.023
URBN	0.580b	0.013	0.188	0.517	0.347b	0.015	1.051c	0.083

Note: "a," "b," and "c" indicate the 1%, 5%, and 10% significance levels, respectively.

Finally, we estimate the unconditional quantile regression models to determine the impact of renewable energy on the carbon emissions and economic output across various quantiles. Table 6 presents the results of this method. The panel quantile findings reveal a positive impact from renewable energy on economic output in coastal provinces in higher quantiles, while its impact on the other panels seems to be insignificant in most cases. Similarly, the results suggest that renewable energy, in lower quantiles, has a negative impact, whereas, in higher quantiles, a positive impact on carbon emissions is observable in coastal and western provinces.

Overall, our empirical results across the techniques imply that the effect of renewable energy on carbon emissions and economic output is almost negligible due to its meagre share in the total energy mix in most of the PRC provinces and/or regions. Given these outcomes, we advise the officials of the PRC to put additional efforts into increasing the share of renewable energy in the total energy mix. The country can achieve this by devoting a significant amount of financial resources to establishing renewable energy projects across the provinces. Further, the officials should frame policies to create a renewable energy market in the PRC. The government should also develop tax incentive policies, particularly for investors who wish to invest in renewable energy projects. The policy makers should also impose higher taxes on firms and individuals that consume non-renewable energy sources. However, before they impose higher taxes on the use of fossil fuel energy, they should ensure sufficient availability of renewable energy for all the users in the country. Further, our results show that the impact of renewable energy on carbon emissions is positive and significant in central provinces, while it has a negative but statistically insignificant effect in coastal and western provinces. Given this evidence, we argue that renewable energy may not reduce the carbon emissions in the country due to low usage across economic activities. Given these arguments, we suggest that policy makers have to make considerable further efforts to improve the share of renewable energy in the total energy mix to witness its positive and negative impacts on the economic output and carbon emissions, respectively, in the country.

Table 6: Panel Unconditional Quantile Regression Models

	0.10		0.20		0.30		0.40		0.50	
	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.
<i>OUTPUT = f(CAP, LBF, HYPO, URBN)</i>										
Full sample										
CAP	0.815a	0.001	0.812a	0.000	0.889a	0.000	1.028a	0.000	1.099a	0.000
LBF	-0.186	0.468	0.146	0.666	0.143c	0.076	0.130	0.478	0.117	0.220
HYPO	-0.172b	0.038	-0.202b	0.026	-0.152b	0.031	-0.173b	0.027	-0.205a	0.009
URBN	-0.549	0.653	0.687	0.514	0.411	0.633	0.518	0.611	0.543	0.530
Constant	4.942	0.188	-1.655	0.654	-1.012	0.657	-2.078	0.459	-2.212	0.385
Coastal										
CAP	0.561	0.607	0.723	0.125	0.870b	0.028	0.883a	0.001	1.058a	0.000
LBF	0.092	0.924	-0.017	0.992	-0.060	0.957	-0.068	0.913	-0.113	0.795
HYPO	-0.041	0.871	-0.269b	0.024	-0.321b	0.032	0.094	0.505	0.190b	0.041
URBN	-1.395	0.629	1.036	0.698	1.959	0.188	1.475	0.128	0.510	0.610
Constant	8.213	0.352	-0.879	0.949	-4.969	0.583	-3.982	0.441	-1.315	0.765
Central										
CAP	1.130a	0.009	0.780a	0.005	0.779a	0.000	0.845a	0.000	0.844a	0.000
LBF	-4.882c	0.074	0.825	0.746	3.716c	0.083	3.598b	0.021	3.899a	0.007
HYPO	-0.159	0.648	0.224	0.413	0.489c	0.096	0.523b	0.047	0.303	0.240
URBN	-0.676	0.709	-1.002	0.472	-2.206c	0.055	-1.520	0.160	-0.579	0.475
Constant	40.164c	0.052	-1.871	0.918	-20.868	0.158	-23.017b	0.044	-27.717a	0.009
Western										
CAP	1.704b	0.045	0.502	0.215	1.036b	0.013	0.614b	0.020	0.560b	0.042
LBF	-0.251	0.409	-0.164	0.591	-0.119	0.716	0.227	0.305	0.207	0.559
HYPO	0.110	0.914	-0.491	0.237	-0.472	0.236	-0.533c	0.083	-0.133	0.624
URBN	-6.219	0.109	2.073	0.379	-0.698	0.780	3.283b	0.023	2.964b	0.024
Constant	17.577b	0.046	-0.506	0.931	5.402	0.417	-7.759c	0.058	-7.685c	0.081
	0.60		0.70		0.80		0.90			
	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.		
<i>OUTPUT = f(CAP, LBF, HYPO, URBN)</i>										
Full sample										
CAP	0.893a	0.000	0.706a	0.000	0.379a	0.003	0.130	0.386		
LBF	0.024	0.892	-0.054	0.636	-0.088	0.562	0.205c	0.096		
HYPO	-0.069	0.600	0.184c	0.071	0.268a	0.006	0.492a	0.001		
URBN	0.804	0.274	0.699	0.390	1.127	0.102	1.275	0.160		
Constant	-1.072	0.651	0.709	0.762	1.931	0.363	0.761	0.783		
Coastal										
CAP	0.979a	0.000	0.827a	0.003	0.574b	0.022	0.490	0.163		
LBF	-0.231	0.676	-0.063	0.928	0.154	0.767	0.118	0.906		
HYPO	0.175b	0.036	0.187b	0.021	0.310b	0.012	0.256c	0.062		
URBN	0.238	0.824	0.548	0.720	0.156	0.923	0.223	0.923		
Constant	1.675	0.738	0.647	0.929	2.629	0.653	3.894	0.696		
Central										
CAP	0.561b	0.017	0.484b	0.027	0.218	0.383	0.649	0.115		
LBF	4.574a	0.001	3.258c	0.052	-1.084	0.717	-7.290c	0.060		
HYPO	0.145	0.588	-0.069	0.770	0.064	0.798	-0.369	0.216		
URBN	0.783	0.414	1.407	0.175	3.268b	0.018	4.238a	0.002		
Constant	-34.913a	0.001	-25.141c	0.054	3.665	0.859	47.368c	0.094		
Western										
CAP	0.665b	0.016	1.167a	0.004	0.961b	0.011	0.567	0.249		
LBF	0.225	0.163	0.161	0.336	0.010	0.961	-0.305	0.426		
HYPO	0.107	0.727	0.427	0.216	0.217	0.651	-0.066	0.908		
URBN	2.425	0.192	-1.745	0.475	-0.806	0.679	0.477	0.842		
Constant	-7.498	0.136	3.009	0.641	3.569	0.446	5.949	0.340		

continued on next page

Table 6 *continued*

	0.10		0.20		0.30		0.40		0.50	
	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.
<i>CDF = f (POP, PI, HYPO, URBN)</i>										
Full sample										
POP	2.050c	0.098	3.330c	0.074	-1.552	0.180	-3.570a	0.000	-4.058a	0.000
PI	-0.299	0.313	0.151	0.574	0.841a	0.001	1.254a	0.000	1.144a	0.000
HYPO	-0.113	0.125	-0.198a	0.009	-0.140b	0.014	-0.135b	0.032	-0.022	0.781
URBN	3.331b	0.038	2.750b	0.029	0.609	0.545	-1.023c	0.067	-1.266a	0.008
Constant	-17.309	0.113	-29.261c	0.061	12.218	0.235	31.145a	0.000	36.910a	0.000
Coastal										
POP	-1.683	0.682	5.384	0.296	-1.772	0.371	-2.326	0.108	-1.474	0.249
PI	0.908	0.573	0.119	0.867	0.867c	0.096	1.279a	0.007	0.978b	0.046
HYPO	-0.064	0.811	-0.279b	0.034	-0.147	0.131	0.065	0.619	0.141	0.203
URBN	-1.544	0.684	1.113	0.731	-0.215	0.920	-1.524	0.447	-0.414	0.858
Constant	19.663	0.542	-40.811	0.329	16.966	0.304	22.345	0.084	13.877	0.260
Central										
POP	10.250c	0.066	2.640	0.535	-2.327	0.435	-7.965a	0.007	-10.889a	0.000
PI	0.260	0.561	0.859a	0.008	1.252a	0.000	1.440a	0.000	1.156a	0.000
HYPO	0.088	0.767	0.047	0.827	-0.106	0.618	-0.150	0.466	0.127	0.511
URBN	1.069	0.572	-0.977	0.435	-2.072b	0.028	-2.721a	0.000	-2.029a	0.004
Constant	-84.251c	0.077	-17.608	0.620	25.474	0.308	74.035a	0.003	97.809a	0.000
Western										
POP	9.918	0.379	6.603a	0.010	10.104a	0.000	5.195b	0.017	1.768	0.383
PI	0.052	0.958	-0.273	0.458	-0.407	0.147	0.253	0.458	0.756b	0.014
HYPO	-0.328	0.585	-0.759b	0.045	-0.645a	0.008	-0.499b	0.012	-0.317	0.172
URBN	1.721	0.703	5.448a	0.001	6.405a	0.000	3.812b	0.019	1.649	0.269
Constant	-74.265	0.398	-56.333a	0.007	-86.200a	0.000	-45.115b	0.011	-15.869	0.343
	0.60		0.70		0.80		0.90			
	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.		
<i>CDF = f (POP, PI, HYPO, URBN)</i>										
Full sample										
POP	-2.816a	0.001	-0.626	0.543	0.583	0.465	0.790	0.338		
PI	1.021a	0.000	0.532b	0.020	0.244	0.212	-0.236	0.221		
HYPO	0.121	0.126	0.208a	0.009	0.275a	0.001	0.326a	0.009		
URBN	-1.453b	0.017	0.179	0.853	0.801	0.406	2.625a	0.004		
Constant	28.236a	0.000	8.720	0.308	-0.720	0.918	-4.485	0.522		
Coastal										
POP	-1.634	0.147	-1.826c	0.098	-1.462	0.181	-1.300c	0.094		
PI	0.928a	0.004	0.612c	0.066	-0.047	0.900	0.164	0.605		
HYPO	0.172b	0.014	0.193a	0.004	0.259a	0.004	0.262b	0.015		
URBN	0.833	0.467	1.531	0.282	3.225b	0.012	1.948	0.240		
Constant	10.917	0.240	13.065	0.183	9.987	0.292	11.917	0.124		
Central										
POP	-13.533a	0.000	-8.362b	0.012	-5.992	0.181	6.829	0.294		
PI	0.676b	0.012	0.372	0.150	-0.216	0.321	-0.279	0.174		
HYPO	0.250c	0.096	0.086	0.635	0.271	0.134	-0.215	0.418		
URBN	-0.129	0.894	1.364	0.195	2.965a	0.003	3.992a	0.001		
Constant	117.208a	0.000	71.764a	0.009	50.846	0.170	-58.098	0.280		
Western										
POP	-4.039b	0.017	-5.085b	0.013	-3.198	0.162	-1.499	0.514		
PI	0.851a	0.003	0.792a	0.010	1.152a	0.003	1.842a	0.000		
HYPO	0.353	0.248	0.524b	0.033	0.331	0.215	-0.014	0.967		
URBN	-0.856	0.550	-0.948	0.480	-2.609c	0.051	-5.276a	0.002		
Constant	34.719b	0.018	43.179a	0.004	32.156c	0.067	23.966	0.176		

Notes: The unconditional quantile regression method is based on the approach that Firpo, Fortin, and Lemieux (2009) suggested; this method accounts for fixed-effects (within) regression; these models were estimated using 100 bootstrap replications; "a," "b," and "c" indicate the 1%, 5%, and 10% significance levels, respectively.

5. CONCLUSION

The present research aimed to explore empirically the effects of renewable energy on the economic output and emissions across the provinces and regions in the PRC. For this reason, we used annual data from 2000 to 2014 and employed a battery of recently developed panel econometric techniques, such as the CD, CIPS, AMG, and unconditional quantile regression methods. This issue is particularly interesting in the context of the PRC due to its increasing global presence in the recent past. More specifically, the contribution of the PRC to the global GDP increased from 4.47% to 11.32% during the period 2000–2014. During the same period, its contribution to the global CO₂ emissions increased from 13.79% to 28.48%. These statistics imply that the PRC accounted for more than one-eighth of the global GDP and one-fourth of the global CO₂ emissions in 2014. These statistics therefore suggest that the increasing economic activities and energy consumption are putting more pressure on the environment in the PRC. During the same period, urbanization also increased from 35.88% to 54.41% of the total population in the PRC. Hence, this paper aimed to understand the nature of the impact of renewable energy consumption on the economic output and CO₂ emissions across the coastal, central, and western provinces of the PRC.

The empirical results of the AMG estimations, which take into account cross-sectional dependence in the analysis, show that renewable energy has an insignificant effect on the economic output across the panels. Further, the results indicate that renewable energy has a negative impact on carbon emissions in the full sample and coastal and western provinces, but again it is insignificant; however, it positively contributes to carbon emissions in central provinces. The results from the unconditional quantile regression methods show that renewable energy has a positive effect on the economic output in coastal provinces in higher quantiles, while its impact on other panels seems to be insignificant in most cases. Similarly, the results suggest that renewable energy in lower quantiles has a negative impact, whereas in higher quantiles it has a positive effect on carbon emissions in coastal and western provinces.

Given this empirical evidence, we argue that the impact of renewable energy on the economic output and carbon emissions is almost negligible in most provinces. This might be because of the small share of renewable energy in the total energy mix in the PRC, which was almost 12% in 2014. This therefore implies that the renewable energy share has to increase considerably to have significant positive and negative impacts on the economic output and carbon emissions in the PRC. Hence, we suggest that policy makers and government officials should adopt further initiatives to take the necessary actions to promote the generation and use of renewable energy in the country to enjoy a high-quality environment for the present and coming generations. Overall, our study provides further knowledge regarding the impact of renewable energy on the economic output and carbon emissions by making use of robust and recent panel econometric techniques. However, the major limitation of our study, due to the unavailability of data, is that we only considered hydropower as a proxy for renewable energy, so future studies could consider all sources of renewable energy to examine its impact on economic growth and emissions across the PRC provinces. Further, future studies could extend the sample period if data become available in the near future.

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