Do Higher Education Research and Development Expenditures affect Environmental Sustainability? New Evidence from Thirty-One Chinese Provinces

Sun Yawen
The Education University of Hong Kong
Qingquan Jiang
Xiamen University of Technology
Shoukat Iqbal Khattak
Jimei University
Manzoor Ahmad (manzoorahmad94@163.com)
Nanjing University Business School https://orcid.org/0000-0002-1152-2096
Hui Li
Xiamen University

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Abstract

Higher education R&D expenditures (HEEXP) are one of the important determinants of economic growth that facilitates science, technology, new ideas, and innovation, but its effect on environmental sustainability remains unexplored. This paper examines the nexus between HEEXP and carbon dioxide emissions (CO_2e), followed by control variables such as electricity consumption, foreign direct investment, gross domestic product, and total population for the period 2000Q1-2019Q4. Some of the key results are as follows. First, the present findings confirmed the long-run cointegration among variables. Second, the finding showed significant long-term negative nexus between HEEXP and CO_2e. Third, the findings indicated that electricity consumption, foreign direct investment, gross domestic product, and total population are the important factors that intensify the overall situation of CO_2e. Fourth, the results indicated that there exist a bi-directional causality between EC and CO_2e; FDI and CO_2e; GDP and CO_2e; POP and CO_2e and HEEXP, and CO_2e.

1 Introduction

Environmental pollution is a major threat to the environment of the world. Rising economic growth and industrialization in emerging economies have fuelled the irresponsible consumption of fossil fuels. Apart from the speedy depletion of natural resources, this situation has contributed to the emanation of more waste, residues, and green-house gases (GHGs) into the environment. These toxic emissions of various types are considered as primary causes of global climate change, rising temperatures, and air pollution. Among them, carbon dioxide is one of the leading pollutants, accounting for about sixty-three percent of the total GHGs (Sharif Hossain, 2011; Wei, 2020). Wei (2020) further reported that the global mean temperature has upsurge by 0.74 centigrade during the last ten decades. Theoretically, the association between gross domestic per capita (GDP) and CO_2e is directly linked to the consumption of different types of carbon-intensive natural resources, especially fossil fuels. Many scholars have argued that CO_2e, fossil fuel consumption, and economic progress are intimately correlated. Researchers have stated that massive industrialization, resulting from an increase in economic activities, escalates the rate of energy consumption from various non-renewable sources, thereby causing CO_2e (Rehman, Rauf, Ahmad, Chandio, & Deyuan, 2019).

From the day China adopted the ‘opening-up policy’, its economy has sharply risen from just RMB0.365 trillion (1978) to RMB8.272 trillion (2007). With a phenomenal upsurge in the GDP (per capita) growth rate, China has now become one of the largest CO_2 emitter in the world (Li, Wu, Lei, Li, & Li, 2019). China has mostly relied on non-renewable energy resources (i.e., coal) to drive its economic growth and industrialization at the cost of high CO_2e, even though it is now cleaning its energy mix (Munir Ahmad & Zhao, 2018). Nonetheless, an overdependency on coal has significantly contributed to global warming, climate change, water contamination, soil erosion, and air pollution in China and the world at large (M. Ahmad et al., 2018). China, with nearly twenty percent of the global population, has significantly affected the economic and environmental landscape of the world. Figure 1 presents the historical growth in population, GDP growth, and CO_2e in China.

For China, economists have extensively measured the environmental impact of CO_2e with different indicators and different econometric techniques. Some of the these economic indicators include financial development (Manzoor Ahmad, Khan, Ur Rahman, & Khan, 2018), inflow of remittances (Manzoor Ahmad, Ul Haq, et al., 2019), urban population (Z. Khan, Shahbaz, Ahmad, Rabbi, & Siqun, 2019), innovation (Khattak, Ahmad, Khan, & Khan, 2020), monetary policy (Qingquan, Khattak, Ahmad, & Ping, 2020), globalization (Akadiri, Alola, Bekun, & Etokakpan, 2020), government expenditures (Le & Ozturk, 2020), foreign direct investment (Munir Ahmad, Zhao, Rehman, Shahzad, & Li, 2019), electricity consumption (Zhang, 2019), GDP (Akadiri et al., 2020), renewable energy consumption (Akadiri, Saint, Alola, Bekun, & Etokakpan,, 2020), information and communication technologies (Mirza, Ansar, Ullah, & Maqsood, 2020), tourism (Aziz, Mihardjo, Sharif, & Jermsittiparsert, 2020), and international trade (Boamah et al., 2017). This paper, however, considers higher education R&D expenditures (HEEXP) as another unexplored determinant of CO_2e for several reasons. First, the HEEXP serves as a core of science, technology, and innovation, which boosts industrialization and economic growth. Thus, this factor is central to CO_2e mitigation strategies. Second, China has long recognized environmental pollution as an urgent threat, and therefore, it has been extensively funding higher education institutions (HEIs) for education and research projects related to energy, green economy, alternative fuel, and non-renewables. In response, the HEIs have actively engaged in the education, research, and development activities by developing new ideas, technologies, products, and processes for the benefit of industry, public, and the environment. Figure 3 depicts the parallel development in the HEEXP and environment-related patents for China for the period 2001–2019, signaling the potential role of HEEXP in eco-related patents. As seen above, a four percent increase in the HEEXP led to a rise in eco-related patents by twenty-one percent in 2016. From 2001–2016, an average of 21.18 percent upsurge in the HEEXP was associated with a parallel increase in eco-related patents by 20.59 percent, cueing potential implication of the HEEXP on eco-related patent development and environmental pollution in China. Despite that, the existing literature fails to offer any published study that sheds light on how shifts in the HEEXP are shaping environmental pollution dynamics.

The key purpose of this study is to fill this knowledge void by comprehensively analyzing the nexus between HEEXP and CO_2e by using data from thirty-one provinces in China. Some significant contributions of this work are as follows. First, the paper provides an initial insight into the potential nexus between HEEXP and CO_2e, thereby opening a possible research avenue in the environmental economics. Second, as of this work, the paper offers the first schematic framework that explains the precise mechanism of how the HEEXP affects environmental pollution in China. Third, the paper uses second-generation econometric techniques for robust and rigorous analysis. Fourth, through provincial data, the paper presents an in-depth insight into regional and provincial disparities vis-a-viz the effect of the HEEXP on CO_2e. Fifth, the article has attempted to integrate two distinct paradigms into a unified framework. Most prior studies on CO_2e in the education literature are limited to the campus-level surveys.

Of the few studies in the economics literature, scholars have used education as a control variable, predominantly using student numbers or percentage of students as proxies. None of the prior studies in both the disciplines have linked the HEEXP to CO_2e.

The rest of the paper is categorized as follows. Section 2 explores the literature review. Section 3, 4, 5, and 6, present the conceptual framework, model specifications, and data sources and variables, and estimation techniques, respectively. Section 7 focuses on the interpretations of results and discussions, followed by the conclusion, policy recommendations, future directions, and limitations in Sect. 8.

2 Literature Review

2.1 The relationship between income and CO_2e

The close inverted U-shape association between environmental sustainability and economic progress has gained considerable significance among scholars, especially during the last three decades. Many believe that rapid economic progress and industrialization affect the environment through the excessive consumption of fossil fuels. Intellectuals have conducted extensive research to find potential determinants of environmental pollution. Past empirical studies have established that dirty and cheap fuel sources (e.g., coal, oil, and natural gas) have been a significant source of increasing global temperature. After the first industrial revolution, entrepreneurs and economies have been striving to control the CO_2e levels to prevent the harmful impact of global warming problems. Environmental Kuznets curve (EKC) hypothesis is probably the most frequently tested framework that explains the link between aggregate income and environmental sustainability (Özcan & Öztürk, 2019). Grossman and Krueger (1991) argued that ecological pollution escalates in the initial stage of economic progress due to intense industrial consumption of cheap energy. This situation, however, improves with increased income as more efficient and clean technologies are used in the production process in the latter stages of economic development. This relationship is commonly referred to as the EKC hypothesis. Several researchers have validated the EKC hypothesis for different economies, including but not limited to, Iberia (Moutinho, Madaleno, & Bento, 2020); China (Jiang, Yang, & Ma, 2019; Mushtaq, Chen, Din, Ahmad, & Zhang, 2020; Zhou et al., 2018); India (Dar & Asif, 2017); Pakistan (Ur Rahman, Chongbo, & Ahmad, 2019); USA (Alola & Alola, 2019); Brazil (Ben Jebli & Ben Youssef, 2019); emerging economies (Wawrzyniak & Doryń, 2020); NAFTA and BRIC (Rahman, Cai, Khattak, & Hasan, 2019); Ukraine (Melnyk, Kubatko, & Kubatko, 2016); SEE economies (Obradović & Lojanica, 2017); developed and developing economies (Anser et al., 2020); and OECD (Manzoor Ahmad, Khan, Rahman, Khattak, & Khan, 2019).

2.2 Relationship between foreign direct investment and CO_2e

The positive link between FDI and CO_2e is known as the pollution-haven-hypothesis (PHH). This concept explains how sources of pollution transfer between countries and regions due to asymmetries in environmental regulations and industrial locations. Prior evidence indicates that pollution-intensive units, factories, or plants facing stringent regulations and policies in first-world economies moved and sought refuge in developing and the third-world economies where laws were either non-extant or extremely weak.

As this trend has continued for long, many developing and third-world nations have become pollution havens due to imported pollution-intensive industries from the developed countries. Besides international trade and foreign investments, weak regulations in these economies have also attracted dirty technologies in most of the emerging economies (Centre, Kiichiro, Masahiro, G, & Alexandra, 2005). That said, the empirical evidence on the FDI-CO2e nexus remains controversial. Some evidence for the positive relationship between FDI and CO_2e include studies for newly industrialized economies (Destek & Okumus, 2019); Cote d'Ivoire (Assamoi, Wang, Liu, & Gnangoin, 2020); ASEAN countries (Guzel & Okumus, 2020); MINT countries (Balsalobre-Lorente, Gokmenoglu, Taspinar, & Cantos-Cantos, 2019); Turkey (Mert & Caglar, 2020); MIKTA economies (Bakirtas & Cetin, 2017); Pakistan (Ur Rahman et al., 2019); Asia (M. A. Khan & Ozturk, 2020); European economies (Mert, Bölük, & Çağlar, 2019); BRI region (A. Khan, Chenggang, Hussain, & Bano, 2019); OIC countries (Ali, Yusop, Kaliappan, & Chin, 2020); and OECD countries (Manzoor Ahmad, Khattak, Khan, & Rahman, 2020).

2.3 The relationship between population and CO_2e

Globally, the historical shifts in demographics have not only resulted in falling fertility, mortality, and population size, but it is also linked to the developments in composition (age-structural change or population aging), distribution (migration), and density (urbanization). Harper (2013) stated that three sub-factors of the population had played an important role in increasing or decreasing CO_2e. Martínez-zarzoso et al. (2007) believed that although economic activity initiates wealth creation in a society, it damages the environment. The authors further added that the production systems in developed economies had generated massive water, air, and soil pollution, while simultaneously depleting precious global natural resources. The detrimental environmental impact of economic activities on the environment has worsened over the past years due to unparalleled demographic growth. With the global population increasing at an unprecedented rate, the resulting expansion in energy consumption has created higher risks for the environment. Researchers have established a definite link between population and CO_2e for European countries (Harper, 2013; Martínez-zarzoso et al., 2007); developed and developing economies (Dietz & Rosa, 1997); selected 93 economies (Shi, 2003); Asian economies (Qingquan et al., 2020); China (Z. Khan et al., 2019; Zhou et al., 2018); MENA economies (Al-mulali, Fereidouni, Lee, & Sab, 2013); newly industrialized nations (Sharif Hossain, 2011); OECD (Liddle, 2013); Pakistan (Ullah, Ozturk, Usman, Majeed, & Akhtar, 2020); OPEC economies (Murshed, Nurmakhanova, Elheddad, & Ahmed, 2020); and Asian countries (Abbasi, Parveen, Khan, & Kamal, 2020).

2.4 The relationship between electricity consumption and CO_2e

Electricity is one of the primary sources of energy for all industries. Even though electricity consumption is not directly associated with CO_2e, the vast quantities of non-renewable fossil fuels used for power generation emit high CO_2e (Zhang, 2019). Previously, few academics have examined the relationship between electricity consumption and CO_2e. For example, Zhang (2019) investigated the relationship between electricity consumption and carbon intensity among twenty-seven firms in China using a STIRPAT framework. The results indicated that electricity consumption played a mitigating role in CO_2e. Balsalobre-Lorente, Shahbaz, Roubaud, and Farhani (2018) concluded that electricity consumption increased CO_2e in the long-run across the European nations. Bélaïd, and Youssef (2017) tested the association between energy (renewable and non-renewable) consumption and CO_2e for Algeria. The ARDL estimates validated the renewable energy consumption-CO_2e led hypothesis. Yorucu and Varoglu (2020) studied the nexus among industrial production, electricity consumption, economic growth, and CO_2e in selected small island states. Based on the FMOLS and DOLS estimations, the authors found that a one percent increase in electricity consumption predicted an upsurge of 0.79 percent in CO_2e. In the same way, others studies have also reported a positive connection between electricity consumption and CO_2e for China (Akadiri et al., 2020; Munir & Riaz, 2020; Ou, Xiaoyu, & Zhang, 2011; Xu, Hong, Ren, Wang, & Yuan, 2015; Zhang, 2019); Spain (Zarco-Soto, Zarco-Periñán, & Sánchez-Durán, 2020); South Asian economies (Munir & Riaz, 2019); Bangladesh (Shahbaz, Salah Uddin, Ur Rehman, & Imran, 2014); ASEAN countries (Lean & Smyth, 2010); Pakistan (Rehman et al., 2019) BRICS (Cowan, Chang, Inglesi-Lotz, & Gupta, 2014; Haseeb, Xia, Saud, Ahmad, & Khurshid, 2019); and Kuwait (Salahuddin, Alam, Ozturk, & Sohag, 2018).

3 Conceptual Framework

Figure 3 illustrates the conceptual framework, depicting the mechanism through which HEEXP may affects CO_2e. For long, the HEIs have been contributing to the advancement of knowledge, economy, cultivating students, and conducting research in many fields. Whether it was the intervention of government or a self-driven agenda, HEIs around the world have undergone enormous transformation and restructuring in areas like organizational practices, research focus, controls, funding structures, and autonomy (Wendt, Söder, & Leppälahti, 2015). Governments' funding, therefore, has been crucial for many HEIs to support basic and advanced level research, especially in fields like environmental sciences, energy and resources efficiency, sustainability, and other similar areas. Many academic institutions have set up separate departments for energy economics, sustainability, green technology, and eco-innovation, while simultaneously initiating programs and activities to achieve green education, green campus, and green economy. With the support of their respective governments, industries, and other institutions, academic institutions are actively conducting research and developing solutions for sustainable production, responsible consumption, and environmental preservation. These projects reflect two facets: i) research on green and sustainability technology, methods, processes, and products; ii) developing and promoting green campuses (GC).

Congruent with the above, academic institutions and governments are equally focused on addressing various crucial issues related to energy consumption and production. A possible explanation resides in the energy resources possessed by a country. If the energy demand exceeds the supply, countries are left with no choice but to import expensive energy from other countries that undermine their security and environment. With the potential role of renewable and green energy, technologies, products, and services, many countries and institutions have been investing heavily in academic research and development related to eco-innovation, green technologies, and renewable energy solutions. As a result, the number of eco-related patent applications and green research has increased manifolds in the past few decades across developed and developing nations. In terms of environmental benefits, these patents have been used across many industries to solve problems, including energy shortages, fossil fuel dependency, and carbon footprint, and low energy efficiency.

Beyond that, academic institutions have been developing and institutionalizing the concept of green campus (GC) and green education. Simply put, GC embodies the development of two critical aspects in an academic institution: a) energy and resource-efficient campus (ERSC); b) campus energy management system (CEMS). The concept of CEMS emphasizes the construction of green education and environmental-related technologies for ERSC. The ERSC, however, requires the integration of green ideology into capital operation, infrastructure, logistics, and other departments. The primary purpose of GC is: to achieve energy and resources efficiency by saving materials, water, energy, land; promote the use of green and clean energy sources during official hours; encourage sustainable development in higher education; improve R&D for faculty, staff, students, and society at large; enhance stakeholder engagement on sustainable decision making; sponsor students and faculty participation in green and sustainability-related activities; and to designing and implement green curricula. Thus, GC plays a vital in the implementation of the sustainable development goals and green policies. Above all, the exchange and cooperation activities among academic institutions for the advancement of GC ideology offer multiple benefits, in terms of national policy formulation for GC development; attainment of Strategic Development Goals, encouraging collaborative research, enabling the diffusion of carbon and energy-saving programs, innovation, and carbon-reduction technology in HEIs, initiating training programs for faculty members, and establishing real-time experiment, labs, and demonstration centers for green research, education, green campus development, and strategy implementation. Through the proper utilization of HEEXP, the GC can find a new way to set the foundations for disseminating the soft power of eco-protection, achieving low-carbon goals, and enabling a smooth transition to a green economy and campus. That said, the development of GC necessitates the need for educational institutions to focus on the hardware and software of GC, simultaneously. The former pertains to the integration of green aspects in construction, building, infrastructure, and operations, and the latter refers to the development and promotion of green culture, humanity, green citizenship, and cultivation of talent for social entrepreneurship. This process, if properly executed, will result in the formation of core green values at all levels (economy, education, society, business), enabling sustainable progress (Tan, Chen, Shi, & Wang, 2014). In short, it is proposed that the development of GC (through HEEXP) not only helps in mitigating CO_2e, but also play an important role in promoting sustainable consumption and production across residential and commercial sectors.

4 Model Specification

Below, Equation (1) represents the dynamic relationship between higher education R&D expenditures (HEEXP), foreign direct investment (FDI), electricity consumption (EC), gross domestic product (GDP), total population (POP), and CO_2e.

$$CO2e_{it} = \psi_o + \psi_1 HEEXP_{it} + \psi_2 FDI_{it} + \psi_3 EC_{it} + \psi_4 GDP_{it} + \psi_5 POP_{it} + \epsilon_{it} \quad (1)$$

Where: CO_2e_{it} = carbon dioxide emissions; $HEEXP_{it}$= higher education R&D expenditures; FDI_{it}= foreign direction investment; EC_{it} = electricity consumption; GDP_{it}= gross domestic product; POP_{it}= total population; ϵ_{it} = error terms; ψ_o = constant; ψ_1, ψ_2, ψ_3, ψ_4, and ψ_5 = the unknown parameters of each variable

The rationale for the use of FDI, EC, GDP, and POP as control variables is briefly discussed henceforth. First, China has become one of the most attractive FDI destinations due to low labor costs and weak environmental regulations. Many multinational companies from developed nations have transferred their technologies (FDI), converting China into a pollution-haven. Second, China is among the top energy generation countries, where almost eighty percent of electricity was generated from coal. Third, it is one of the largest economies in the world, vis-a-viz the GDP growth rate. Fourth, China is one of the most populous economies in the world, where population growth has created contributed to energy consumption among residential and non-residential consumers, directly and indirectly causing CO_2e.

5 Data Sources And Variables

The data for HEEXP, FDI, EC, GDP, POP, and CO_2e were collected from the National Bureau of Statistics (2019) for the period 2000 to 2019. Consistent with the previous studies (Sbia, Shahbaz, & Hamdi, 2014; Shahbaz, Hoang, Mahalik, & Roubaud, 2017), the accuracy and frequency of the data were enhanced through the quadratic match-sum method. All variables were converted into logarithmic forms for added reliability and consistent results. Table 1 shows the data sources and descriptions.

Table 1
Data description and sources.

Variables	Notation	Units	Source of data	Estimation technique	Expected signs
Electricity Consumption	EC	Watt-hour	National Bureau of Statistics (2019)	Quadratic match-sum method	Positive
Foreign direct investment	FDI	Million Yuan	National Bureau of Statistics (2019)	Quadratic match-sum method	Positive
Gross Domestic Product	GDP	100 million Yuan	National Bureau of Statistics (2019)	Quadratic match-sum method	Positive
Population	POP	10000 people	National Bureau of Statistics (2019)	Quadratic match-sum method	Positive
Research & development expenditures in the higher education sector	HEEXP	1000 Yuan	National Bureau of Statistics (2019)	Quadratic match-sum method	Negative
Carbon dioxide emissions	CO_2e	10000 tons	National Bureau of Statistics (2019)	Quadratic match-sum method	

6 Estimation Techniques

6.1 Unit root testing

Testing the cross-sectional dependence (CSD) among the series was the first step in the panel data analysis. This test was conducted to identify and deal with the problems of unit-root and CSD in the data series. As the CSD is associated with factors, including, economic union, financial shocks, demand shocks, supply shocks, pandemic diseases, globalization, and trade wars, it must be dealt with accuracy and precision. If ignored, it could be led to bias cointegration and stationarity results (Z. Khan, Ali, Jinyu, Shahbaz, & Siqun, 2020). The Pesaran (2015) cross-sectional dependence test (PCSDT) and the M.H Pesaran and Yamagata (2008) slope homogeneity test (SHT) were applied for addressing the CSD and homogeneity problems, respectively. In the next step, the order of integration was examined for all variables using the second-generation Pesaran and M.H (2003) (PMCADF) and Pesaran (2007) (PCIPS) unit-root tests. Conventional or first-generation panel unit-root tests are based on the hypothesis of cross-sectional independence (CSI). The second-generation unit-root tests, however, allow for the assumption of CSD in the data series. With the results of second-generation tests providing strong evidence on the existence of CSD across the provinces in China, these tests were appropriate for estimating the order of integration. For robustness check, the Clemente, Montañés, and Reyes (1998) unit root test (CMRURT), with multiple structural breaks was employed the aggregate data on EC_i, FDI_t, GDP_t, POP_{it}, $HEEXP_t$, and CO_2e_{it}.

6.2 Cointegration testing

For cointegration testing, this study adopted the Westerlund (2007) error-correction-based panel cointegration test (WECPT). The author proposed four cointegration tests to examine the presence of long-run cointegration in the panel data. These tests are based on the error-correction (EC) model and offer three distinct advantages: 1) it allows unbalanced panels and unequal series length in units; 2) tests heterogeneity that is permitted in the short- and long-run parameters of the error-correction model; 3) obtains critical value using the bootstrap approach, if a correlation probability exits among units. The WECPT involves the following hypothesis:

H_0 *:No cointegration exists among all panels*

H_1 *:Cointegration exists among all panels*

The paper adopted three cointegration tests for checking robustness—Kao (1999) residual-based cointegration test (KRCPT), Pedroni (2004) cointegration test (PCT), and the Gregory and Hansen (1996) cointegration test (GHCT) (with structural breaks and regime shifts).

6.3 Long-run coefficients estimation

Several economic techniques have been introduced in the past decades for addressing the CSD and parameter heterogeneity problems. Some of the widely accepted methods include the M. Hashem Pesaran and Smith (1995) mean group (MG) estimator, M. Hashem Pesaran (2006) common correlated effects mean group (CCEMG) estimator, and the Eberhardt and Bond (2009) augmented mean group (AMG). Technically, the MG method separately applies times-series ordinary least square (OLS) to each panel, including a linear trend to estimate time-variant unobservable (TVU), and an intercept to deal with fixed components. Then, this estimator averages the computed individual-specific slope (without or with wrights). For dynamic cases, this estimator proves to be reliable for large N and T, if the coefficients exhibit heterogeneity in groups. This estimator, however, fails to offer information about common factors

(CFs), which may exist in the panel data. The CFs are referred to as time-specific effects, which are common in provinces, countries, or regions. By incorporating the averages of the cross-sections of the independence and the dependent variables as surplus regressors when applying OLS to specific units, the CCEMG method allows for TVU and CSD with heterogenous effect in panel members. Identified by the averages of CS, the unobserved CF can be any fixed digit. With superior small sample characteristics and short-run estimation properties, the CCEMG technique is relatively robust to non-cointegrated and non-stationary CF, structural breaks, and some serial correlations. As an alternate method, the AMG initially computes an augmented pooled model (with year dummies) through the first difference OLS. The calculated year dummies are then compiled to construct a new variable, representing the common dynamic process. This new variable is used as an extra regressor for single group-specific regressor model, along with an intercept for capturing the time-variant fixed impacts. Similar to the CCEMG technique, the AMG method helps in dealing with multi-factors error-terms and non-stationary variables, particularly considering CSD. The AMG estimator is superior to the CCEMG, in terms of creating a set of unobservable CF as a common dynamic process. Dissimilar to a scenario in which the unobservable factors are considered as a nuisance, the alternate treatment may offer helpful interpretations, depending on the context (Heshmati, 2019).

6.4 Panel causality testing

For panel data, Dumitrescu and Hurlin (2012) proposed a test to examine causal relationships between variables. This test outperforms the traditional causality tests by allowing for the hypothesis of causality existence in at least one cross-section, against the non-existence of homogenous Granger-causality relationship. In this way, the Dumitrescu and Hurlin (2012) panel-causality test (DHPCT) accounts for the CSD between the sample province or countries. Moreover, the DHPCT is insensitive to the variance among the cross-sections and the time difference in the panel. It generates efficient results, even if the size of the cross-sections and time series are smaller or larger than others (Ceyhun, 2019).

7 Results And Discussion

Table 2 depicts the results of PCSDT. As seen below, the null hypothesis of no CSD for the EC_{it}, FDI_{it}, GDP_{it}, POP_{it}, $HEEXP_{it}$, and CO_2e_{it} was rejected at 10, 5, and 1 percent significance levels. This implied that all the provinces in China were interdependent in a way that an economic shock in one region may affect other regions, too. As reported in Table 3, the SHT highlighted heterogeneity problems in the model.

Table 2
Results of the PCSDT.

Variable	CD-statistic	P-value	Average joint T	Meanρ	Mean obs (ρ)
CO_2e	148.205	0.000	80.00	0.77	0.86
EC	168.425	0.000	80.00	0.87	0.96
FDI	153.638	0.000	80.00	0.80	0.80
GDP	189.912	0.000	80.00	0.98	0.98
POP	56.194	0.000	80.00	0.29	0.48
HEEXP	150.963	0.000	80.00	0.78	0.81

Note. CO_2e = Carbon dioxide emissions; EC = Electricity consumption; FDI = Foreign direct investment; GDP = Gross domestic product; POP = Population, HEEXP = Higher education R&D expenditures.

Table 3
Results of the SHT.

Statistics	Test value	P-value
Delta	82.524	0.000
Adjusted Delta	86.391	0.000

Table 4 displays the results of the PCADF and PCIPS unit-root tests. These tests were used to check the integration order of all the study variables. The results confirmed that all the study variables were non-stationary at level but became stationary at the first difference, even though these tests were unable to deal with structural breaks in the data. Given that most global economies have experienced many structural changes, it is considered imperative to trace structural breaks in the data series for China. There was a high probability that the PCADF and PCIPS could be given bias results, if structural changes were underestimated. This problem was addressed through the CMRURT that allowed for multiple structural breaks in the data.

Table 4
Results of the PCADF and the PCIPs unit-root tests (without structural breaks).

	At level		**At first difference**	
Variable	PCADF	PCIPS	PCADF	PCIPS
CO_2e	0.588	-0.335	-9.307***	-3.942***
EC	3.226	-1.866	-3.374***	-4.161***
FDI	1.140	-0.727	-4.176***	-4.467***
GDP	2.028	-0.703	-16.727***	-3.186***
POP	20.072	-1.704	-23.227***	-3.222***
HEEXP	13.596	-1.295	-12.026***	-4.250***

Note. CO_2e = Carbon dioxide emissions; EC = Electricity consumption; FDI = Foreign direct investment; GDP = Gross domestic product; POP = Population, HEEXP = Higher education R&D expenditures. *** indicates 1% level of significance.

Table 5 illustrates the results of the CMRURT. The test indicated that all variables were stationary at the first difference, with two break years in each series. The estimated structural breaks—often linked to global or local events—had potential positive or negative implications for the Chinese economy. In 2002, a deadly virus named SARS emerged in Guangdong and severely impacted industrial production (Wong & Zheng, 2004). In 2004, China faced one of the worst historic inflationary pressures, partly triggered by real-estate speculations. With an increase in the costs of raw material and energy and over-investments in some industries, China raised interest rates and applied administrative control to abate the pace of investment in some sectors and industries (Morrison, 2010). In 2005, Lenovo Group acquired the personal computer division of IBM for a hefty sum of USD1.75 billion. Indeed, this acquisition is considered as an economic breakthrough. Apart from gaining access to foreign, facilities, operations, and R&D, China strengthened its presence in the US (Morrison, 2010). From 2008–2009, the global financial crisis pushed China to revisit its economic policies to sustain economic growth. While the economic growth rate was disrupted in 2009 relative to the past years, this slowdown in growth was reasonably modest, especially when compared with the total shrinkage in the world output (Lardy, 2012). Although the incoming FDI experienced a sharp decline, the inbound foreign investments reached an all-time high in 2010, increasing by around two-third, i.e., USD185 billion. There was almost twenty percent contraction in outbound FDI in 2009, but the outbound FDI increased by thirty-seven percent and touched an all-time high of USD60 billion (Lardy, 2012). Moreover, the inclusion and internationalization of RMB in the Special Drawing Rights currency basket by the IMF in 2010 was another important milestone, which enabled China to expand its financial presence in the global financial markets (Cassis & Wójcik, 2018). With all the study variables exhibiting the same integration order, the study applied the cointegration analysis, including the WECPT, KRCPT, PCT, and the GHCT.

Table 5
Unit root test with structural breaks.

	At level		At first difference	
Variable	t-statistic	Breakpoints	t-statistic	Breakpoints
CO_2e	1.438	2002Q3, 2017Q3	-5.779***	2010Q4, 2016Q4
EC	0.842	2009Q2, 2012Q3	-2.287**	2006Q4, 2009Q4
FDI	1.360	2015Q1, 2017Q2	-4.722***	2001Q3, 2015Q1
GDP	1.442	2009Q3, 2010Q3	-4.337***	2003Q1, 2008Q4
POP	0.050	2004Q4, 2005Q3	-8.438***	2003Q4, 2004Q4
HEEXP	0.916	2008Q1, 2011Q3	4.187***	2010Q4, 2011Q4

Note. CO_2e = Carbon dioxide emissions; EC = Electricity consumption; FDI = Foreign direct investment; GDP = Gross domestic product; POP = Population, HEEXP = Higher education R&D expenditures. **, *** indicates 5% and 1% level of significance, respectively.

Table 6 depicts the outcomes of the cointegration analysis without structural breaks. The first two columns (G_t, G_a) indicate the group means statistics for the total cointegration, whereas the remaining two columns (Pa, Pt) show panel statistics. The WECPT outputs confirmed a sustainable long-term association among all the study variables. In Table 7, the results of the cointegration analysis with structural break and regime shifts were found to be consistent with the WECPT, KRCPT, and the PCT.

Table 6
Cointegration analysis without structural breaks.

Test statistics	$CO_2e \rightarrow EC$	$CO_2e \rightarrow FDI$	$CO_2e \rightarrow GDP$	$CO_2e \rightarrow POP$	$CO_2e \rightarrow HEEXP$
WEPCT					
Gt	-2.098**	-2.059**	-12.575***	-5.554***	-4.362***
Ga	-116.59***	-44.50***	-43.088***	-29.438***	-128.47***
Pt	-3.411***	1.449	-2.087**	-1.750**	0.861
Pa	-7.055***	1.738	-1.534*	-1.148	0.011
KRCPT					
MDF_t	4.57***	-18.94***	-0.21	-1.23	1.59*
DF_t	5.60***	-10.94***	-4.02***	0.07	-1.85**
ADF_t	-2.27**	-13.20***	-7.08***	-3.32***	-6.26***
$UMDF_t$	5.53***	-9.65***	1.47***	-0.9653	2.17**
UDF_t	8.18***	-11.15***	-3.04***	0.23	-1.35*
PCT					
MDF_t	4.66***	3.92***	3.57***	-3.24***	2.64***
PP_t	9.10***	1.65*	7.87***	-2.78***	6.01***
ADF_t	21.11***	2.89***	21.29***	3.76***	14.52***

Note: WEPCT = Westerlund (2007) error-correction based panel cointegration tests; KRCPT = Kao (1999) residual-based tests for cointegration in panel data; MDF_t= Modified Dickey-Fuller t; DF_t= Dickey-Fuller t; ADF_t= Augmented Dickey-Fuller t; UMD_t= Unadjusted Modified Dickey- Fuller t; UDF_t= Unadjusted Dickey-Fuller t; PCT = Pedroni (2004) cointegration test; PP_t= Phillips-Perron t; ADF_t= Augmented Dickey-Fuller t; CO_2e = Carbon dioxide emissions; EC = Electricity consumption; FDI = Foreign direct investment; GDP = Gross domestic product; POP = Population, HEEXP = Higher education R&D expenditures.

*, **, *** indicates 10%, 5% and 1% level of significance, respectively.

Table 7
Cointegration analysis with structural break and regime shifts.

Test statistics	$CO_2e \rightarrow EC$	$CO_2e \rightarrow FDI$	$CO_2e \rightarrow GDP$	$CO_2e \rightarrow POP$	$CO_2e \rightarrow HEEXP$
Change in Level					
ADF	-6.11***	-32.14***	-6.53***	-9.41***	-8.72***
Breakpoint	54	36	52	56	38
Break year	2013Q2	2009Q1	2012Q4	2013Q4	2009Q2
Critical values (1%)	-5.13	-5.13	-5.13	-5.13	-5.13
Critical values (5%)	-4.61	-4.61	-4.61	-4.61	-4.61
Critical values 10%)	-4.34	-4.34	-4.34	-4.34	-4.34
Change in Regime					
ADF	-5.56***	-5.80***	-9.54***	-8.73***	-8.92***
Breakpoint	55	61	36	36	45
Break year	2013Q3	2015Q1	2008Q4	2008Q4	2011Q1
Critical values (1%)	-5.47	-5.47	-5.47	-5.47	-5.47
Critical values (5%)	-4.95	-4.95	-4.95	-4.95	-4.95
Critical values 10%)	-4.68	-4.68	-4.68	-4.68	-4.68

Note: CO_2e = Carbon dioxide emissions; EC = Electricity consumption; FDI = Foreign direct investment; GDP = Gross domestic product; POP = Population, HEEXP = Higher education R&D expenditures.

*** indicates a one percent level of significance.

Table 8 displays the long-run coefficients based on three different econometric methods, including the MG, AMG, and CCMEG. The main findings are as follows. First, the estimates showed a significant negative linkage between HEEXP and CO_2e—a one percent increase in HEEXP predicted a decline of .29 (MG), 0.24 (AMG), and 0.30 (CCEMG) percent in CO_2e. As predicted, this result supported that spending on research and development spending in higher education has helped to mitigate CO_2e in China. A feasible explanation is that academic institutions have been a central part of the national research framework, in terms of developing green technology, innovation, and eco-urban systems in China. In 2011 alone, the faculty and staff from HEIs constituted 11.3 percent of the overall research and development population. Using almost 8.5 percent of the total national R&D spending, these researchers have shown impressive results. These individuals conducted 62.2 percent of the all research projects and activities, received 28.8 percent of the total patents, applied for 21.6 percent of the total patents, and produced 64.4 percent of the entire scientific publications. Following the ‘new normal’ of fostering the nation with education, science, innovation, and developing a green economy, the Chinese government has placed a significant focus on green and sustainable technology research. Currently, Chinese scholars are the leading the global research related to green production, sustainability, green technology, environment, and green energy. More so, the government has been allocating a considerable amount of funds for sustainability-oriented R&D projects. From 2000–2009, these funds have increased from just RMB7.67 billion to RMB46.7 billion, constituting almost eight percent of the total national spending on R&D. A total of RMB14.5 billion were allocated to basic research, accounting for nearly fifty-three percent of the total national research budget (Hu, Liang, & Tang, 2017).

Next, China initiated the *211 Project* and *985 Project* to uplift the standard of its HEIs. These projects were aimed at developing globally competitive first-class universities, programs, and scientific disciplines to promote sustainable and green socio-economic development in China. Hu, Liang, and Tang (2017) argued that the fifteen years of the *211 Projects* have been extremely fruitful, in terms of setting the foundations for green innovation in education, research and service, and transitioning to a green economy. China spends around two percent of its total GDP on research, an amount that is increasing at the rate of twenty percent per year (Chung, 2015). Under the government's guidance, Chinese HEIs have dedicated time, resources, and money for research on green energy, economy, technology, education, and innovation to realize a green revolution (Liu, Strangway, & Feng, 2012). These factors have played an instrumental role in indirectly mitigating CO_2e by raising awareness, development of green technology, and green urbanization, and green education.

In the same vein, China has been investing heavily in the green university/campus project. Many top-ranking and globally-recognized universities have joined hands with the government to realize the Sustainable Development Goals. For Instance, Tsinghua University has been championing the idea of green campus (GC), green technology, and green education. Peking University initiated the green university project in April 2009. As an initial step, the planning department was rebranded as the Campus Planning and Sustainable Development Office. Beijing University has set four key objectives for achieving the GC and educational goals: 1) spatial design augmentations of the university; 2) improved and continued excellence of scientific research and teaching; 3) propagation and restoration of culture and environmental heritage; and establishment of zero-carbon campus (Morgan, Gu, & Li, 2017). Lee and Efird (2014) further explained the idea of green universities by identifying some key attributes. Firstly, these universities place acute emphasis on environmental education and integrate environmental aspects in the teaching, research, and curriculum. Secondly, the student and faculty master the knowledge, skills, and expertise on topics related to environmental protection, sustainable development, and environmental awareness. Thirdly, the members of the green universities actively engage in the society-focused programs for environmental publicity, evaluation, and education. Fourthly, the environment becomes an important part of the campus culture, and it is integrated into all campus policies to develop a cleans and green campus environment. Gou (2019) added that green campus operations are linked to all areas, including, labs, classrooms, transportation, dormitories, and other facilities. Thus, the idea of green campus and green education entails several economic benefits, especially for a massively-populated country like China. The GC can help to save energy, water, and other precious resources in China, particularly if the consumption of energy and water among HEIs is higher than the residential consumers. Apart from enabling the generation of new ideas and patents for green production, innovation, technology, and economy, the macro impact of the GC resides in improved efficiency and social fairness in the usage of natural resources. For ecological advantages, all HEIs need to revisit their effects on energy efficiency by transforming their facilities to preserve the environment. Beyond that, the social benefits of the GC include the conversion of students and teachers into conscious and eco-friendly consumers. Thus, the GC has the potential to reduce deprivation and poverty among regions or provinces, enhance fairness, and to expand the sustainable growth concept in the Chinese society. All these measures, if implemented correctly, can decrease CO_2-related energy consumption and increase the use of clean technologies across China. Table 9 exhibits the parallel fluctuations in HEEXP and CO_2e.

Table 8
Long-run coefficients.

Variables	MG	AMG	CCEMG
HEEXP	-0.294*** (-4.91)	-0.242***(-4.63)	-0.303***(-3.87)
	[0.059]	[0.052]	[0.078]
FDI	0.427***(6.59)	0.118***(2.78)	0.341***(6.16)
	[0.067]	[0.042]	[0.055]
GDP	0.445***(3.19)	0.748***(8.67)	0.637***(6.57)
	[0.139]	[0.086]	[0.097]
POP	0.686***(4.53)	0.922***(3.98)	0.683***(3.58)
	[0.151]	[0.232]	[0.191]
EC	0.522***(3.48)	0.383***(6.15)	0.308***(3.14)
	[0.1444]	[0.062]	[0.098]
C	1.169***(3.85)	2.6223***(9.10)	32.551***(13.31)
	[0.304]	[0.288]	[2.126]

Note. CO_2e = Carbon dioxide emissions; EC = Electricity consumption; FDI = Foreign direct investment; GDP = Gross domestic product; POP = Population, HEEXP = Higher education R&D expenditures. () = t-statistic; [] = standard error; MG = Mean group; AMG = augmented mean group; CCEMG = Common correlated effect mean group.

*** indicates a one percent level of significance.

Second, the long-run coefficients indicated a significant positive linkage between FDI and CO_2e, offering empirical evidence for the acceptance of the PHH in China. A one percent increase in FDI caused a rise in CO_2e by 0.42 (MG), 0.12 (AMG), and 0.34 (CCEMG) percent. This result suggested that some cities, provinces, and municipalities in China, with less stringent regulations, have become pollution havens in an attempt to attract FDI and pollution-intensive industries. This result validated the previous studies conducted for China (Ur Rahman et al., 2019); OECD (Manzoor Ahmad et al., 2020); newly industrialized nations (Destek & Okumus, 2019); Cote d'Ivoire (Assamoi et al., 2020); ASEAN (Guzel & Okumus, 2020); MINT countries (Balsalobre-Lorente et al., 2019); Pakistan (Nadeem, Ali, Khan, & Guo, 2020; Naz et al., 2019); MIKTA economies (Bakirtas & Cetin, 2017); BRICS (Z. U. Khan, Ahmad, & Khan, 2020); Arab countries (Abdo, Li, Zhang, Lu, & Rasheed, 2020); Asian countries (M. A. Khan & Ozturk, 2020); and European countries (Mert et al., 2019). However, this results contradicts the previous studies conducted for coastal Mediterranean countries (Nathaniel, Aguegboh, Iheonu, Sharma, & Shah, 2020); OECD (Manzoor Ahmad, Khan, et al., 2019); Turkey (Mert & Caglar, 2020); China (Ayamba, Haibo, Ibn Musah, Ruth, & Osei-Agyemang, 2019; Hao, Wu, Wu, & Ren, 2020); and Kyoto Annex countries (Mert & Bölük, 2016).

Third, the estimations revealed a positive association between GDP and CO_2e—a one percent increase in GDP led to a rise in CO_2e by 0.44 (MG), 0.75 (AMG), and 0.64 (CCEMG) percent. This result suggested that GDP growth—driven by low energy efficiency and coal consumption—had enhanced CO_2e in China. This result is consistent with the previous findings for India (Dar & Asif, 2017); Pakistan (Chandia, Gul, Aziz, Sarwar, & Zulfiqar, 2018; Ur Rahman et al., 2019); China (Manzoor Ahmad et al., 2018; Mushtaq et al., 2020; Wei, 2020; Zhou et al., 2018); the US (Alola & Alola, 2019); Liberia (Moutinho et al., 2020); Qatar (Mrabet, AlSamara, & Hezam Jarallah, 2017); selected 72 countries (Inekwe, Maharaj, & Bhattacharya, 2019); developing countries (Wawrzyniak & Doryń, 2020); NAFTA and BRIC (Rahman et al., 2019); SEE countries (Obradović & Lojanica, 2017); and Asian economies (Qingquan et al., 2020).

Table 9
Parallel fluctuations in HEEXP and CO_2e.

Province	Year	Quarter	HEEXP (%)	CO_2e (%)
Beijing	2002	I	0.03↑	0.485↓
Beijing	2008	II	0.306↑	0.399↓
Tianjin	2003	I	0.498↑	0.266↓
Tianjin	2016	IV	0.002↑	0.078↓
Hebei	2006	I	2.151↑	0.209↓
Hebei	2009	I	0.373↑	0.177↓
Shanxi	2006	I	0.146↑	0.245↓
Shanxi	2013	II	0.093↑	0.117↓
Inner Mongolia	2003	I	0.842↑	1.319↓
Inner Mongolia	2013	I	0.126↑	0.607↓
Liaoning	2000	I	0.881↑	2.189↓
Liaoning	2019	I	0.714↑	0.655↓
Jilin	2012	I	0.070↑	0.261↓
Heilongjiang	2004	IV	1.012↑	0.946↓
Heilongjiang	2016	III	0.187↑	0.188↓
Shanghai	2011	I	0.504↑	0.121↓
Shanghai	2014	I	0.354↑	0.548↓
Jiangsu	2017	II	0.178↑	0.139↓
Jiangsu	2018	I	0.806↑	0.992↓
Zhejiang	2017	III	0.0081↑	0.268↓
Zhejiang	2019	I	0.522↑	0.686↓
Anhui	2004	I	0.832↑	0.303↓
Anhui	2018	I	1.414↑	1.071↓
Fujian	2015	IV	0.357↑	0.183↓
Fujian	2018	II	0.189↑	0.817↓
Jiangxi	2012	I	0.113↑	0.604↓

Province	Year	Quarter	HEEXP (%)	CO_2e (%)
Jiangxi	2014	I	0.212↑	0.390↓
Shandong	2006	I	0.888↑	0.191↓
Shandong	2019	I	1.136↑	0.133↓
Henan	2012	I	0.744↑	0.317↓
Henan	2015	I	0.055↑	0.184↓
Hubei	2008	I	0.101↑	0.222↓
Hubei	2018	I	2.135↑	1.042↓
Hunan	2004	I	0.650↑	0.168↓
Hunan	2013	II	0.112↑	0.104↓
Guangdong	2013	I	0.472↑	0.137↓
Guangdong	2018	I	0.638↑	1.117↓
Guangxi	2002	I	3.644↑	0.388↓
Guangxi	2015	I	0.080↑	0.444↓
Hainan	2015	IV	1.253↑	0.185↓
Chongqing	2003	II	0.744↑	0.253↓
Chongqing	2013	III	0.449↑	0.131↓
Sichuan	2006	I	0.814↑	0.205↓
Sichuan	2017	II	0.159↑	0.154↓
Guizhou	2004	I	1.6099↑	0.142↓
Guizhou	2010	I	0.795↑	0.211↓
Yunnan	2003	III	0.484↑	0.307↓
Yunnan	2010	I	0.779↑	0.135↓
Xizang	2006	II	0.489↑	0.105↓
Xizang	2016	III	0.125↑	0.191↓
Shanxi	2009	I	0.839↑	0.171↓
Shanxi	2019	I	1.722↑	0.763↓
Gansu	2011	I	0.849↑	0.182↓
Gansu	2016	I	0.284↑	0.194↓

Province	Year	Quarter	HEEXP (%)	CO_2e (%)
Qinghai	2013	I	2.716↑	0.114↓
Qinghai	2017	I	3.029↑	0.379↓
Ningxia	2004	II	0.293↑	0.459↓
Ningxia	2016	I	0.668↑	0.713↓
Xinjiang	2012	I	1.439↑	0.607↓
Xinjiang	2017	II	0.111↑	0.303↓

Fourth, the long-term coefficients demonstrated a positive connection between population and CO_2e—a one percent increase in population contributed to a rise in CO_2e by 0.69 (MG), 0.92 (AMG), and 0.68 (CCEMG) percent. This finding implied although the growing aging populace would lower the rate of future CO_2e, it would also create the need for developing alternative models of economic growth for a smooth transition into a green economy. Nonetheless, this result supported the previous results for China (Z. Khan et al., 2019; Zhou et al., 2018); Asian economies (Khoshnevis Yazdi & Dariani, 2019; Qingquan et al., 2020); developing economies (Martínez-zarzoso et al., 2007); MENA countries (Al-mulali et al., 2013); newly industrialized nations (Sharif Hossain, 2011); and the EU nations (Kasman & Duman, 2015).

Fifth, the results revealed a positive electricity use-CO_2e nexus, implying that the irresponsible consumption of electricity (by educational, residential, and industrial consumers) had significantly enhanced CO_2e in China. This finding points towards the heavy reliance on carbon-intensive energy sources (e.g., coal, and oil) for domestic and industrial consumers by the power generation sector. That said, the new energy policies and installed-capacity forecast suggest that the over-dependency on fossil-fuels will reduce significantly in the future, thereby decreasing CO_2e. The commercial sector (e.g., tech companies) is also setting the foundations for responsible energy consumption by switching from conventual to renewable energy sources. As some tech companies have started using solar and wind for power generation, other sectors will also follow this campaign to reduce their carbon footprint. This result validates the previous studies conducted for China (Akadiri et al., 2020; Munir & Riaz, 2020; Xu et al., 2015; Zhang, 2019); Spain (Zarco-Soto et al., 2020); South Asian economies (Munir & Riaz, 2019); Bangladesh (Shahbaz et al., 2014); ASEAN countries (Lean & Smyth, 2010); Pakistan (Rehman et al., 2019) and BRICS (Haseeb et al., 2019).

Finally, Table 10 exhibits the results of the DHPCT. The causality estimates revealed a bi-directional causality between EC and CO_2e; FDI and CO_2e; GDP and CO_2e; POP and CO_2e and HEEXP, and CO_2e. These results suggested that government policies that target EC, FDI, GDP, POP, and HEEXP have, directly and indirectly, led to an increase or decrease in CO_2e.

Table 10
Results of the DHPCT.

Relationship	W-Stat	Zbar-Stat
EC→CO_2e	15.5470***	35.5125***
CO_2e →EC	11.0489***	23.6718***
FDI→ CO_2e	8.90131***	18.0186***
CO_2e →FDI	14.9115***	33.8397***
GDP→ CO_2e	15.3180***	34.9098***
CO_2e →GDP	13.8654***	31.0861***
POP→ CO_2e	16.9784***	39.2807***
CO_2e →POP	18.1091***	42.2570***
HEEXP → CO_2e	7.11697***	13.3215***
CO_2e →HEEXP	12.0309***	26.2569***

Note: CO_2e = Carbon dioxide emissions; EC = Electricity consumption; FDI = Foreign direct investment; GDP = Gross domestic product; POP = Population; HEEXP = Higher education R&D expenditures. *** indicates a one percent level of significance.

8 Conclusion And Policy Implications

The main objective of this study was to explore potential long-run connections between the HEEXP and CO_2e for thirty-one provinces in China from 2000(Q1) to 2019(Q4). The panel data were analysed using the multiple econometric techniques. First, the results of the WECPCT, KRCPT, and PCT indicated that a long-term cointegration existed between all the study variables. Second, the MG, AMG, and CCEMG supported that the HEEXP had disrupted CO_2e, while EC, FDI, POP, and GDP had a positive interaction with CO_2e in the long run. Third, the DHPCT reflected that a two-way causal relationship existed between CO_2e and all other study variables—FDI, EC, GDP, POP, and HEEXP.

The following important implication were drawn from current findings. Firstly, the current findings assert the need for the policymakers to design specific policies for green education, green campus, green economy. Chinese government should extend financial support to encourage its academic institutions for developing green patents and conducting research on projects related to energy efficiency, sustainable production, green consumption, and preservation of land, soil, and environment. With the nascent awareness of environmental standards and norms, an extensive capacity building is across all academic institutions to align these institutions with global standards, eco-innovation, and sustainability practices. Second, the current results also require the need for the adjustment of research themes with the national energy and sustainable development plans. For this purpose, the HEEXP policy should be designed in a manner that the rewards, incentives, bonuses, and funding for academic institutions are based on the quality and quantity of eco-related patents and research. These institutions should be directed to develop matrices aligned with national themes and sustainability targets, including but not limited to clean and efficient transport technologies, solar thermal technology, solar cells, wind power, new nuclear power systems, carbon capture and sequestration, clean coal, ecological conservation, grassland development, recycling economy, biofuels, bioproducts, and integrated gasification combined systems.

Third, the acceptance of the PHH in this study has strengthened the previous argument that FDI in developing countries have enhanced dirty technologies. Thus, policymakers are expected to tighten the environmental regulations, ensure that foreign enterprises transfer clean technologies, and improve green investment. Fourth, the positive connection between CO_2e and electricity use calls for not only revisiting the existing energy mix, but also asserts the need for devising energy efficiency strategies to curb CO_2e. Policymakers should, therefore, continue to clean and expand the energy mix with more renewables for electricity generation to meet future demand. While encouraging and supporting the commercial sector to deploy solar and wind for power generation, the government should formulate energy efficiency policies for resources management, regardless of its types, i.e., non-renewable or renewable energy. If inefficiently managed, these resources face the risk of depletion. Thus, the future policies for a green economy should incorporate efficient resources management, solar and wind energy development, technology improvements, carbon-taxing, and green urbanization. Of particular significance, all these policies should be designed, integrated, and coordinated with multiple stakeholders (i.e., community, government, academia, and administration) for effective execution and results.

Fifth, the current findings concerning the adverse effect of the population on the environment assert the need for developing a responsible and eco-driven aging sector. This argument stems from the fact that a significant majority of the existing population in China is predicted to experience aging, leaving a wide gap in the workforce in the future. While this phenomenon may decrease the level of CO_2e, it necessitates the need policies that guarantee better healthcare, social justice, social security, and other related facilities across all provinces. If this issue is underestimated, the socially deprived and unsatisfied populace may contribute to CO_2e, thereby disrupting the green transformation. Thus, policymakers should devise policies to encourage investments in the aging sector to address the potential future disruption in economic growth. That said, this new sector should be built on the foundations of energy-saving, responsible consumption, social equality, income equality, old-age security, and equal access to quality healthcare for all provinces.

This study has some limitations that open new doors for future research. First, this study had only focused on China. The same model can be used for other developing and developed economies. Second, this study applied linear econometric techniques (MG, AMG, and CCEMG) to explore the relationship between HEEXP and CO_2e. Perhaps, some non-linear models (e.g., NARDL) can be used to explore the same relationship and variables in a unified framework. Third, the current has adopted the EKC framework for examining different relationships. Researchers are encouraged to tests the current findings using the STIRPAT framework for new insights.

Declarations

Ethical Approval

Not applicable

Consent to Participate

Not applicable

Consent to Publish

Not applicable

Authors Contributions

Sun YAWEN: Conceptualization; Data curation; Formal analysis

Qingquan JIANG: Investigation; Methodology; Project administration

Shoukat I KHATTAK: Software; Supervision; Validation

Manzoor AHMAD: Writing - original draft; Writing - review & editing

Hui LI: Writing - original draft; Writing - review & editing

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Competing Interests

The authors declare that they have no competing interests.

Data availability

The datasets used and/or analyzed during the current study are variability from the corresponding author on reasonable request.

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Figures

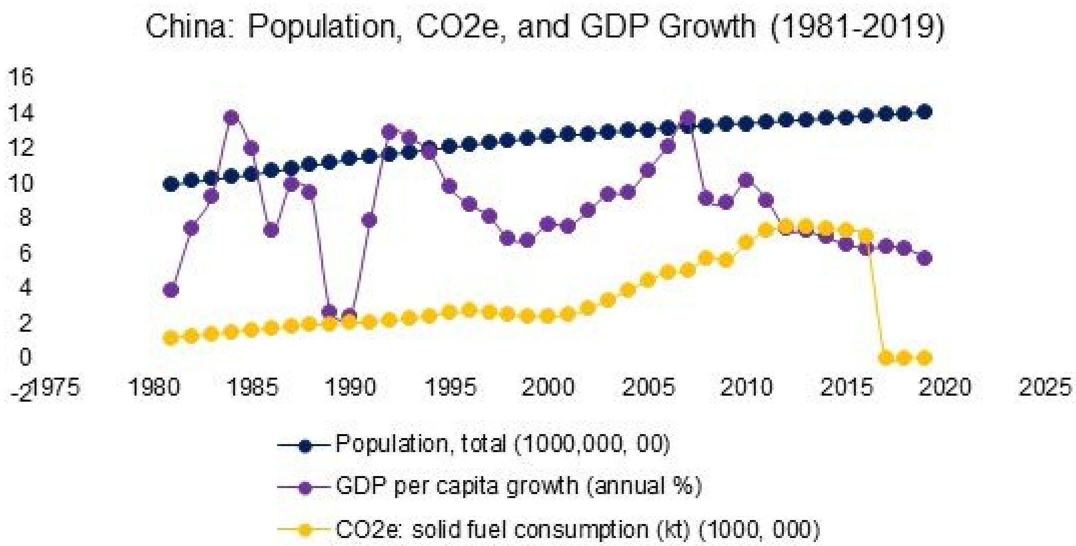

Figure 1

A comparison of CO2e, population, and GDP growth in China (1981-2019).

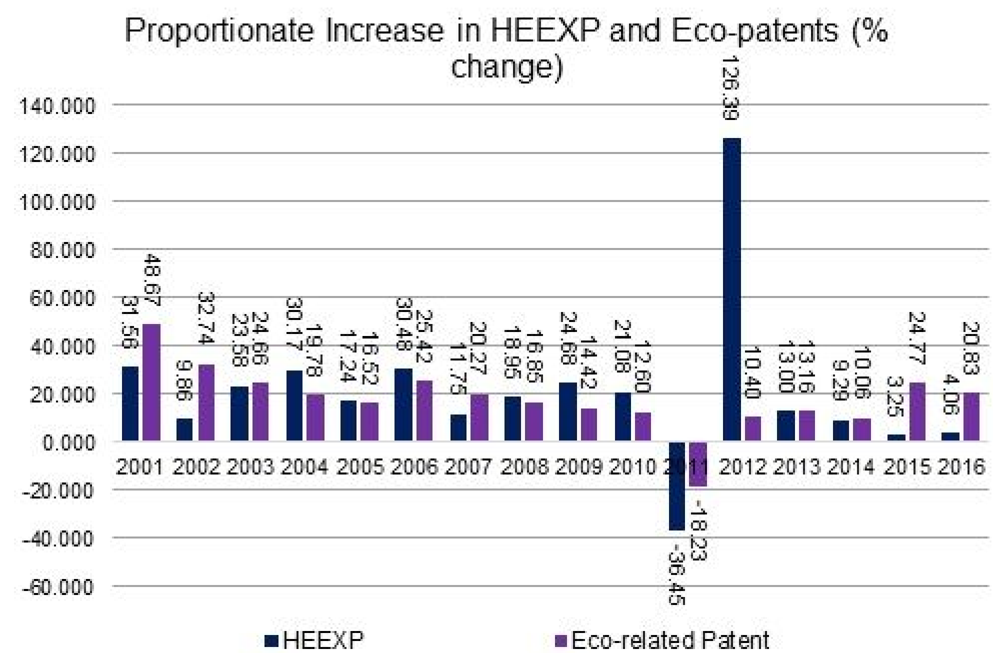

Figure 2

Proportionate changes (%) in HEEXP and eco-related patents.

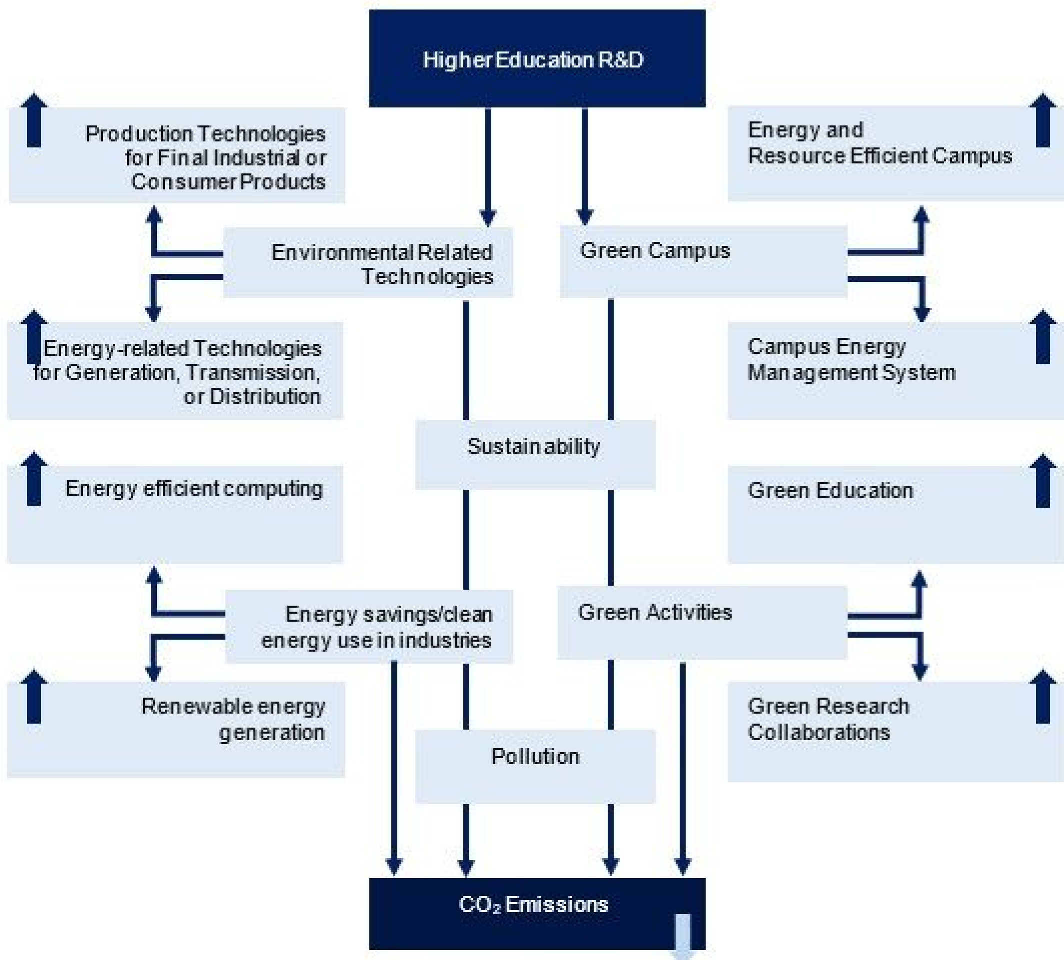

Figure 3

The conceptual framework.