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RESEARCH ARTICLE

Educational attainment and environmental Kuznets curve in China: an aggregate and disaggregate analysis

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Abstract
The primary focus of this study is to evaluate the impact of various levels of education on CO2 emissions in China. Moreover, the study also tested the EKC hypothesis for different levels of education and economic development. The analysis employed disaggregate and aggregate data for education that included enrollment at primary, secondary, and tertiary levels and the average year of schooling. For empirical analysis, we employed an error correction model and bounds testing approach to cointegration. The results of the study provided some useful information both in the short and long run. All the proxies of education positively impact CO2 emissions at the initial level both in the short and long run; however, when we take the square of these variables, the effects of education on CO2 emissions become negative. Similarly, the impact of economic growth on CO2 emissions is positive in the short and long run, and the square of economic growth on CO2 emissions is negative, supporting the EKC hypothesis. China should increase investment in human capital that promotes green growth and environmental quality.

Keywords Education · Environmental Kuznets curve · China

Introduction

Many policymakers, governments, and economists view sustained development and the worldwide impact of China as both alarming and impressive. China raised almost half of its deprived population above the poverty line in a very short period (Shen et al. 2018 and Li et al. 2021a, b). Apart from several regional disparities, economic, and social issues, this change occurs at the cost of severe environmental issues. OECD (2018) highlighted that although leading worldwide rankings in various groups, including exports and imports, FDI, China is also at front-runner position for production and consumption of energy, carbon emissions, and greenhouse gas emissions. Nonetheless, China is very much committed to making efforts for attaining the Sustainable Development Goals (SDGs). In the United Nations General Assembly conference of 2015, the member states vowed to eradicate poverty and hunger, provision of quality-based and equal education opportunities, reduction in carbon emissions, nitrogen gas, and certain other detrimental pollutants (Tiwari et al. 2020 and Yan et al. 2021). Modifications in economic and social factors such as knowledge, innovation, income, and FDI can enhance the environmental quality during the path of economic development (Aslam et al. 2021; Jafri et al. 2021; Jan et al. 2021; Ullah et al. 2021). However, literature reported that economic factors are more responsible as compared to social factors for CO2 emissions (Hamid et al.2020; Jinru et al. 2021; Mujtaba, et al. 2021; Mujtaba and Jena 2021).

In the view of researchers, education may contribute significantly to solving various ecological, economic, and

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social issues (Yin et al. 2021). As a social paradigm, education works as an influential instrument for altering lives, as it helps in improving innovation capabilities, skills, and knowledge of the economies (Bangay 2016). Meanwhile, education helps in enhancing the quality of the environment by creating consciousness about pollutants and environmental issues and helps in circulating compulsory wisdom mandatory for the enactment of green standards of living, green production, eco-innovation, and carbon decline policies for attainment of viable future, particularly for developing economies (Khattak et al. 2020). The policymakers and researchers argue that higher education and economic growth are closely related due to several implications for technological development and knowledge. But the empirical literature is insufficient on the nexus between environmental pollution and higher education, revealing that economists and environmentalists have paid diminutive consideration to this imperative issue (Uddin 2014). The available literature on this issue represents two strands of research. The first strand infers that education plays a significant positive role in reducing CO2 emissions, and the second strand of literature demonstrates on-campus accomplishments for higher CO2 emissions.

First strand of literature claims that education increases CO2 emissions through numerous educational activities. For example, the study done by Caird et al. (2015) investigated the education-carbon footprint nexus for 15 higher educational institutions in the UK. The findings of the study reveal that on-campus educational activities result in increasing carbon emissions; however, online educational activities result in reducing CO2 emissions. The study highlighted some factors that are linked with on-campus educational activities, such as consumption of energy construction, and certain other campus-related operation. For Japan, Parra et al. (2018) reported that teaching activities, studies, and on-campus miscellaneous work contributed significantly to raising CO2 emissions. Versteijlen et al.'s (2017) study for the Netherland highlighted that frequent traveling by students and staff are the main source of high carbon emissions and online educational setup tends to reduce global and regional CO2 footprint. The literature highlighted some other determinants of carbon emissions that are directly linked with on-campus educational activities such as air transportation (staff and students sometimes travel through long distances), food, housing activities, consumption, and mobility (Sippel et al. 2018).

The second strand of literature argues that education exerts a significant negative impact on carbon emissions through various transmission channels. Li and Zhou (2019) examined that how demographic structure and higher education affect carbon emissions at the national and provincial levels in China. The study reported a negative relationship between higher education and CO2 emissions in the case of East China. Uddin (2014) concluded that an increase in educational expenditures augments green economic growth and mitigates carbon emissions through increased awareness. A bulk of literature infers that improvement in the education sector mitigates carbon emissions (for example, Sarwar et al. 2019; Subramaniam and Masron 2020). Conversely, the study done by Balaguer and Cantavella (2018) investigated the linkage between environmental quality and education in the context of the environmental Kuznets curve (EKC) framework. The study reported harmful impacts of higher education on environmental quality in the early stages, but afterward, when the education level achieves a certain threshold, it starts improving the quality of the environment. Educational attainment can be used to mitigate CO2 emissions via environmental awareness, energy efficiency, green technology, and green growth (Çakar et al. 2021; Mankiw et al. 1992; Yang et al. 2017). Human capital is used to adopt new technologies and pollution-free sources in the industrial sector (Dasgupta et al. 2000), which in turn improves the environment. Educational attainments can significantly alleviate environmental costs (Manderson and Kneller 2012). In the end, a detailed summary of the empirical literature is reported in Table 1.

China has taken several initiatives in its higher education field in terms of higher education institutes, quality of education, and student enrollment. An extraordinary increase has been observed in both the number of student enrollments and the number of higher education institutions from the time period 2000 to 2019. For example, the number of students has increased from 9.398 million to 40.02 million, and the number of institutes has increased from 1813 to 2688 during this period. Furthermore, the expenditures on the education sector have increased up to 26% of the GDP in this period. Regardless of the anticipated theoretical importance of education, the CO2 emission and education association remain widely unexplored in the literature of environmental economics. The empirical findings from available studies provide mixed evidence on the linkage between education and CO2 emissions. Some scholars reported a positive impact of education on CO2 emissions, and others demonstrated the negative impact of education on CO2 emissions (for instance, Balaguer and Cantavella 2018; Sippel et al. 2018; Li and Zhou 2019). In the case of China, there is only one study available that investigated the impact of higher education on CO2 emissions for East China by using total student enrollments in thirteen higher education institutes as a proxy for measuring higher education and reported a negative impact of higher education on CO2 emissions.

The linkage between CO2 emissions and educational attainment has been explored in previous literature, but there exist various shortcomings that need to be considered. Firstly, existing studies have explored the nexus between human capital and CO2 emissions at an aggregate level; little attention is given to disaggregated level analysis. Secondly, although existing studies have explored the impact of

Table 1 Summary of literature

Author(s)	Region/country	Time span	Methods	Independent variables	Outcomes
Çakar et al. (2021)	EU	1994–2018	PSTR	Human capital	Human capital declines CO2 emissions in the low growth regime while falls in the high growth regime
Zafar et al. (2021)	Top remittance-receiving countries	1986–2017	CUP-FM and CUP-BC	Education	Education exacerbate CO2 emissions
Yao et al. (2020)	OECD	1870–2014	AMG and PMG	Human capital	Human capital strongly negative impact on CO2 emissions
Khan (2020)	Global	1980–2014	Threshold model	Education	Education is essential for reducing the CO2 emissions
Khan et al. (2021)	OECD	1990–2018	CS-ARDL	Human capital	Human capital has a positive effect on CO_2 emissions
Lin et al. (2021)	China	2003–2017	SYS-GMM	Human capital	Human capital support environmental sustainability
Wang and Xu (2021)	Global	1995–2018	SYS-GMM	Human capital	Human capital has an inverted U-shaped relationship with CO2
Li and Ullah (2021)	BRICS	1991–2019	NARDL	Human capital	A positive change in education has mitigated CO2 emissions
Rahman et al. (2021)	Newly industrialized countries	1979–2017	FMOLS,DOLS,PMG	Human capital	Human capital improved environmental quality
Ahmed et al. (2020)	G7	1971 to 2014	CUP-FM and CUP-BC	Human capital	Human capital has a favorable impact on the environment
Dauda et al. (2021)	Africa	1990 to 2016	CS-ARDL	Human capital	Human capital decreases CO_2 emissions
Mahmood et al. (2019)	Pakistan	1980 to 2014	3SLS	Human capital	Human capital mitigates CO_2 emissions
Duarte et al. (2012)	Spain	1999	SAM	Primary, secondary, and tertiary	A lower level of education increase CO2
Ullah et al. (2020)	Pakistan	1980–2018	ARDL	Human capital	Human capital has an insignificant impact on CO_2 emissions
Li et al. (2021a, b)	China-Provinces	2000–2018	FMOLS and DOLS	Higher education	Higher education shows a positive role in declining CO_2 emissions
Bano et al. (2018)	Pakistan	1971 to 2014	ARDL	Human capital	Human capital reduce carbon emissions
Li and Zhou (2019)	China-regions	1996–2015	FMOLS	Higher education	Higher education has a positive influence on CO2

educational attainment on CO2 emissions, the importance of educational attainment in the EKC hypothesis framework is still unexplored. Thirdly, considerable literature has explored the association between educational attainment and CO2 emissions, but no clear consensus has been achieved yet. Lastly, a lot of literature addresses the educational attainment implications for CO2 emissions based on cross-country data, but the said relationship has not been explored for China yet. Thus, our primary objective of the study is to fill the knowledge gap in environmental economics by examining the EKC hypothesis for different levels of education and economic development.

This study contains both practical applications and theoretical contributions. Considering the theoretical contribution, this study will strengthen and enrich the existing literature in the context of EKC hypothesis using aggregate and disaggregate levels of education. It will help in understandings the effects of educational attainment on CO2 emissions. On the practical ground, this study aims at providing important implications for China to design more appropriate strategies for educational attainment, environmental sustainability, and green growth. Moreover, these implications can also be considered for other developed and developing high-polluted economies. This study endorses the significant role of educational attainment for environmental sustainability and design appropriate policy measures to achieve a clean environment.

Model and method

The theoretical base of the model is derived from the EKC model. The EKC model was first presented by Grossman and Krueger (1995), which confirmed the inverted U-shaped relationship between GDP and CO2 emissions. According to the EKC hypothesis, at the initial level of economic development, CO2 emissions rises, and at the later stage of the economic development, CO2 emissions decline (Hamid et al. 2021 and Isik et al. 2021). Balaguer and Cantavella (2018) augmented the EKC model for Australia with the variables of education. Following them, we also have augmented the EKC model of China with different variables of education. Hence, the baseline looks as follows:

$$CO2_t = \beta_0 + \beta_1 X_t + \beta_2 LnY^2{}_t + \beta_3 LnZ_t + \varepsilon_t \quad (1)$$

where the dependent variable is CO2 emissions, a proxy of environmental degradation. X is a set of main variables that include primary education (PE), secondary education (SE), tertiary education (TE), the average total years of schooling (AE), and economic growth (GDP). Then, Y^2 is a set of variables where we have taken the square of each of the main variables such as a square of primary education (PE^2), square of secondary education (SE^2), square of tertiary education (TE^2), square of average total years of schooling (AE^2), and economic growth (GDP^2). Lastly, Z_t is a set of control variables that include energy consumption (EC), individuals using the internet (Internet), and government expenditure (GE). Model (1) is only offering the long-run estimates. To find the short-run outcomes with the long run, we reformulate the basic model in an error correction format. Our extended model is shown below:

$$\Delta CO2_t = \beta_0 + \sum_{k=1}^{n1} \beta_{1k} \Delta CO2_{t-k} + \sum_{k=0}^{n2} \beta_{2k} \Delta X_{t-k} + \sum_{k=0}^{n3} \beta_{3k} Y^2{}_{t-k} + \sum_{k=0}^{n4} \beta_{4k} Z_{t-k} + \gamma_1 CO2_{t-1} + \gamma_2 X_{t-1} + \gamma_3 X^2{}_{t-1} + \gamma_4 Z_{t-1} + \varepsilon_t \quad (2)$$

Equation (2) is an error-correction model where coefficient estimates β_{1k}, β_{2k}, β_{3k}, and β_{4k} reveal short-run effects and estimates of γ_1,γ_2,γ_3, and γ_4 are long-run effects. A former study of Pesaran et al. (2001) recommends two diagnostic tests (e.g., *F*-test and *t*-test) to establish cointegration (Sohail et al. 2021). *F*-test null hypothesis is that H0: $\gamma_1=\gamma_2=\gamma_3 = \gamma_4=0$ but the alternative is H1:$\gamma_1\neq 0,\gamma_2\neq 0,\gamma_3\neq 0$, and $\gamma_4\neq 0$. The alternative hypothesis infers the existence of a long-run relationship among concern variables. Indeed, under the ARDL approach, variables could be a mixture of I(1) and I(0). Long-run as well short-run effects can be easily judged in a single step via ARDL. The ARDL method has been used in empirical research works in numerous contexts (Usman et al. 2021a, b) which advice that the ARDL model is more suitable for short- and long-run analysis. The ARDL offers different estimates in short and long run at different lags order in a model. The ARDL diagnostic tests are also equally suitable with short- and long-run estimates (Lei et al. 2021). Thus, to check for serial correlation, we employ the Lagrange multiplier (LM) test. We use the Breusch–Pagan (BP) test to measure the heteroskedasticity and Ramsey's RESET test to find misspecification. Finally, CUSUM and CUSUM-sq tests are described to judge the stability of the long- and short-run coefficient estimates.

Data

The study aims to investigate the role of educational activities in determining the EKC in case of China for time horizon 1991 to 2019. The dependent variable EKC is measured by carbon dioxide emissions and greenhouse gas emissions. The study utilizes four proxies to measure the role of educational activities in China such as primary education, secondary education, tertiary education, and average education. These education levels are measured as school enrollments at gross percentage of primary, secondary, and tertiary levels; however, average education is measured as average total years of schooling. Some other variables namely GDP per capita measured at constant 2010US$, energy consumption in kg of oil equivalent per capita, use of internet in the percentage of the population, and general government final consumption expenditures in the percentage of GDP are taken as control variables. Table 2 gives us information about variables and definitions. Data for all variables have been sourced from the World Bank and the human development index.

Results and discussion

Our aim in this study is to investigate the role of school enrollment at various levels in the formation of the EKC in China. To get estimates of the variables, we employ the ARDL model. ARDL has various advantages over other techniques, but the foremost advantage of this technique is

Table 2 Variables and definitions

Variables	Symbol	Definitions
CO2 emissions	CO2	CO2 emissions (kt)
Greenhouse gas emissions	GHG	Total greenhouse gas emissions (thousand metric tons of CO2 equivalent)
Primary education	PE	School enrollment, primary (% gross)
Secondary education	SE	School enrollment, secondary (% gross)
Tertiary education	TE	School enrollment, tertiary (% gross)
Average years of schooling	AE	Average total years of schooling
GDP per capita	GDP	GDP per capita (constant 2010 US$)
Energy consumption	EC	Energy use (kg of oil equivalent per capita)
Internet users	Internet	Individuals using the Internet (% of population)
Government expenditure	GE	General government final consumption expenditure (% of GDP)

that it performs well even if the variables are a mixture of I(0) and I(1). However, we cannot include the variables of I(2) in the analysis. Therefore, to confirm that none of the included variables is I(2), we employ two unit root tests, one without a structural break and another with a structural break. Table 3 provides the findings of both the unit root tests. From the results, we can deduce that most of the variables are I(1) and some are I(0) by using either of the tests; however, none of the variables in the analysis is I(2). These findings give us a positive signal that we can apply the ARDL model. Another important thing that needs to be decided before starting our formal discussion is selecting the appropriate lag. Our data is annual, and we apply a maximum of two lags, and to choose the correct number of lags, we use Akaike information criterion (AIC).

We have used four different proxies for education for empirical analysis: enrollment at primary, secondary, and tertiary levels. Moreover, we also include the average total years of schooling to get the accumulative impact of education on the CO2 emissions. First, we discuss the short-run estimates, and after that, we discuss the ones in the long run.

Table 4 illustrates the short-run and long-run results of the ARDL model. In short run, the estimated coefficient of D(PE) is positively significant, and the estimate of D(PE^2) is negatively significant. Similarly, the estimate attached to D(SE) is positive, and the estimate attached to D(SE^2) is negative and significant. Then the estimate attached to D(TE) is positively significant, whereas the estimate attached to D(TE^2) is negatively significant. Lastly, the estimates attached D(AE) is positive at first lag, and the estimate attached to D(AE^2) is negatively significant at first lag. These findings confer that increased enrollment at all levels does increase the CO2 emissions; however, at the later stage, increased enrollment at all levels decreases the CO2 emissions. The estimated coefficients of D(GDP) are positively significant in all models, and the estimates attached to D(GDP^2) are negatively significant, confirming

Table 3 Unit root testing

	Unit root without break test			Unit root with break test				
	I(0)	I(1)	Decision	I(0)	Break date	I(1)	Break date	Decision
CO2	−0.898	−4.689***	I(1)	−5.025***	2002			I(0)
GHG	−0.725	−2.657*	I(1)	−5.932***	2002			I(0)
PE	−2.654*		I(0)	−4.452**	2001			I(0)
SE	−0.325	−4.965***	I(1)	−4.332	2006			I(0)
TE	−0.356	−2.887*	I(1)	−0.897	2012	−6.231	2014	I(1)
AE	−1.789	−7.654	I(1)	−3.323	2018	−6.689	2002	I(1)
GDP	−0.875	−2.635*	I(1)	−3.201	2002	−4.356*	2007	I(1)
EC	−0.456	−3.678*	I(1)	−4.821**	2002			I(0)
Internet	−0.623	−2.658*	I(1)	5.398***	2006			I(0)
GE	−2.671*		I(0)	−5.164	2015			I(0)

***$p<0.01$; **$p<0.05$; and *$p<0.10$

Source: Author's calculation

Table 4 ARDL estimates of CO2 emissions

	Primary education		Secondary education		Tertiary education		Average education	
	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat
Short run								
D(PE)	2.618***	2.763						
D(PE(-1))	−1.561	1.482						
D(PE^2)	−3.229***	2.782						
D(PE^2(-1))	2.021	1.432						
D(SE)			3.371	0.435				
D(SE(-1))			9.660*	1.832				
D(SE^2)			−0.515	0.540				
D(SE^2(-1))			−1.210*	1.835				
D(TE)					0.010*	1.772		
D(TE(-1))					0.003	1.043		
D(TE^2)					−0.039*	1.885		
D(AE)							0.429	0.783
D(AE(-1))							2.449***	3.070
D(AE^2)							0.032	0.853
D(AE^2(-1))							−0.177***	3.019
D(GDP)	1.153**	2.133	1.894***	3.406	1.045**	1.989	1.825***	3.032
D(GDP(-1))	0.479	0.822			0.567	1.172	0.866	1.578
D(GDP^2)	1.376*	1.760	2.169**	2.879***	2.310	3.512***	1.289**	1.981
D(EC)	0.859***	2.783	1.255***	5.846	1.105***	5.135	1.527***	5.892
D(EC(-1))	0.447	1.444					−0.429	1.275
D(Internet)	−0.002	0.510	−0.003*	1.828	−0.005*	1.843	−0.011**	2.150
D(Internet(-1))	0.008***	2.756			−0.009**	2.414	-0.019*	1.752
D(GE)	0.008	0.466	−0.013	1.070	−0.004	0.426	0.233	0.123
D(GE(-1))	0.036*	1.699						
Long run								
PE	1.570**	2.182						
PE^2	−2.058**	2.164						
SE			1.218*	1.755				
SE^2			−0.171**	1.986				
TE					−0.008***	2.983		
TE^2					0.023*	1.921		
AE							0.580***	3.436
AE^2							−0.039***	3.266
GDP	0.270	0.196	0.353	0.318	0.002	0.022	0.386**	2.330
GDP^2	−0.879**	2.065	−0.456*	1.867	−0.231*	1.661	−0.776**	2.101
EC	1.194***	5.733	1.431***	3.599	1.174***	9.466	1.568***	4.218
Internet	0.001	0.118	−0.002*	1.835	−0.001*	1.880	−0.002*	1.952
GE	−0.002	0.123	−0.019***	2.823	−0.017***	3.181	−0.012*	1.840
C	−5.114	2.071	3.334***	2.301	7.299	2.245	5.401***	7.866
Diagnostics								
F-test	13.12		12.10		13.12		9.789	
ECM(-1)	−0.471***	6.729	−0.592***	9.563	−0.652***	9.521	−0.578***	7.307
LM	1.298		1.023		0.398		1.785	
BP	0.325		0.875		0.795		1.035	
RESET	0.689		1.487		0.980		2.033	
CUSUM	S		S		S		S	
CUSUM-sq	S		S		S		S	

***$p < 0.01$; **$p < 0.05$; and *$p < 0.10$

Source: Author's calculation

the presence of EKC in the short run. Given the importance of long-run results, we now pay attention to the long-run estimates provided in Table 4. The validity of the long-run results depends on the confirmation of cointegration between them. To that end, we rely on two tests of cointegration, i.e., *F*-test and ECM_{t-1}, and the results of both the tests are provided in Table 4, which confirm that cointegration exists among the CO2, SE, PE, TE, AE, GDP, EC, Internet, and GE.

The long-run estimates attached to PE, SE, TE, and AE are positively significant, or more precisely, we can say that a 1% rise in primary, secondary, tertiary, and aggregate enrollment increases the CO2 emissions by 1.570%, 1.218%, 0.008%, and 0.580%. Conversely, the estimates attached to PE^2, SE^2, TE^2, and AE^2 are negatively significant, or in terms of elasticity, we can say that a 1% rise in PE^2, SE^2, TE^2, and AE^2 causes the CO2 emissions to decline by 2.058%, 0.171%, 0.023%, and 0.580%. This result is consistent with Duarte et al. (2012), who infer that a lower level of educated consumers produces more CO2 emissions in Spain. Our findings are also backed by various studies such as Li et al. (2021a, b), who argued that improvement in human capital through higher education can raise awareness among people regarding the utilization of environment-friendly technologies, thus reducing CO2 emissions. Furthermore, it is supported by the argument that development in human quality reduces the abatement activities that tends to a significant decline in CO2 emission. In contrast, Li and Zhou's (2019) study argues that higher education tends to increase CO2 emissions in the highest income most developed region of China.

Generally, our findings imply that an increase in educational activities at all levels increases the CO2 emissions at the early stages; however, later on, education reduces the CO2 emissions. In other words, the relationship between CO2 emissions and all levels of education follows an inverted U-shaped path, implying that CO2 emissions increase in the early parts of increased educational activities and decline at the later stages. As the demand for education in the country increases, on one side, more educational infrastructure such as schools, colleges, universities, and hostels are required; on the other side, demand for transportation facilities, laundry, dry cleaning, and saloon services will also increase (Sippel et al. 2018). As a result, the energy demand rises, which is a primary driver of CO2 emissions. However, the positive effects of education on the environment may come later once the education sector starts producing more trained, skilled, capable, and efficient human resources that can replace the more energy-intensive inputs in the production process and ultimately reduce CO2 emissions.

Social and economic activities performed by humans cause emissions, and education is an important source that can positively alter human behavior (Jian et al. 2021). Moreover, education help raise the technical skills and capabilities that will improve human efficiency in all walks of life and contribute to economic development (Usman et al. 2021a, b). Experts of economics strongly agree that human capital is essential for the economic growth of a country in the long run. They also agree that human capital is a by-product of formal education, trained and experienced labor, and research and development, which are fundamental parts of the inputs used in the production function (Wang and Shao 2019). Most developing economies have replaced their labor-intensive production techniques with human capital intensive ones and achieved the economic goals with a more clean environment. However, the evidence suggests that education may pollute the environment in developing and emerging economies due to energy-intensive infrastructure and low economic development (Mahalik et al. 2021). The energy consumed by educational activities at various levels may differ at different stages of economic development (Inglesi-Lotz and Morales, 2017), which may form an inverted U-shaped relationship between education and CO2 emissions.

As far as the long-run relationship between economic development and environmental quality is concerned, we can see that the estimates attached to GDP are positive but insignificant in most models. However, the estimates attached to GDP^2 are negatively significant in all models confirming the presence of an inverted U-shaped relationship between economic development and CO2 emissions in China. Such an inverted U-shaped relationship is known as the EKC of Grossman and Krueger (1995), which implies that the early part of economic growth pollutes the environment and later improves it. This result also implies that China is heading towards sustainable development, i.e., achieving economic growth without polluting the environment further. The estimate of the control variable of EC suggests that increased energy consumption causes the CO2 emissions to rise; however, the estimates of Internet and GE are significant and negative, implying that increased internet subscriptions and government expenditures cause the CO2 emissions to decline in China.

Finally, to confirm the efficiency of our estimates, some diagnostic tests are also outlined in Table 4. Firstly, Lagrange multiplier (LM) test confirms that our residuals are free from first-order serial correlation. Secondly, the Ramsey RESET test confirms that no misspecification is found in our model. Thirdly, Breusch Pagan (BP) test approves that the variance of the error terms is homoscedastic. Finally, the CUSUM and CUSUMSQ confirm the parametric stability of the models where "U" represents the stable parameters and "US" represents the unstable parameters. Sensitivity analysis is also done in order to gauge the robustness of empirical results by using greenhouse gas emissions as dependent variables. The findings of the robust model are given

Table 5 ARDL estimates of greenhouse gas emissions (GHG)

	Primary education		Secondary education		Tertiary education		Average education	
	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat
Short run								
D(PE)	2.231*	1.929						
D(PE(-1))	−1.263***	2.714						
D(PE^2)	−3.362*	1.913						
D(PE^2(-1))	1.727***	2.693						
D(SE)			2.466***	4.834				
D(SE(-1))			−0.824***	3.695				
D(SE^2)			−0.908***	4.940				
D(TE)					0.205**	2.369		
D(TE(-1))					0.128**	2.516		
D(TE^2)					−0.026*	1.802		
D(AE)							0.074	0.812
A(AE(-1))							0.186**	2.679
D(AE^2)							−0.117	0.233
D(AE^2(-1))							−0.847***	2.593
D(GDP)	1.319**	1.967	1.508***	4.054	1.054	1.395	1.948***	2.623
D(GDP(-1))	0.272**	2.275			0.222	0.364		
D(GDP^2)	1.012	1.044	1.360	0.365	0.986***	2.875	1.042*	1.954
D(EC)	1.430***	9.851	0.592***	6.183	0.937***	11.23	1.235***	8.746
D(EC(-1))	−0.372	1.248	0.762***	4.348	0.550***	3.152	−0.217	1.008
D(Internet)	−0.006**	2.375	−0.001	0.464	−0.001	0.320	−0.001	0.477
D(Internet(-1))	0.009**	2.516	0.009**	2.846	0.005*	1.708		
D(GE)	0.013	1.508	0.012**	2.216	0.020***	3.736	0.023***	2.880
D(GE(-1))	0.000	0.030	−0.010	1.621	−0.006	1.182	−0.014	1.517
Long run								
PE	1.497***	2.776						
PE^2	−2.770***	2.784						
SE			1.042***	6.319				
SE^2			−0.528***	6.535				
TE					−0.129*	1.942		
TE^2					0.017*	1.862		
AE							0.456**	1.974
AE^2							−1.088*	1.867
GDP	1.767**	2.349	1.950***	4.346	1.600	1.408	1.925**	2.544
GDP^2	−1.022**	1.233	1.552*	1.689	−1.225	1.025	−1.055***	2.654
EC	1.376***	5.141	0.974***	9.183	1.162***	6.092	1.466***	9.308
Internet	−0.001	1.275	−0.003***	3.143	−0.001	0.931	−0.001	0.478
GE	−0.025**	2.351	−0.001	0.491	−0.009***	3.882	−0.029***	4.099
C	−2.186**	2.325	5.617***	4.091	5.812***	2.654	5.628***	3.153
Diagnostics								
F-test	13.12***		16.32***		14.25		9.587***	
ECM(-1)*	−0.523***	4.816	−0.619***	4.661	−0.559***	3.606	−0.476***	11.19
LM	2.050		1.586		2.012		1.587	
BP	0.785		0.654		1.021		0.452	
RESET	1.320		0.875		1.587		2.023	
CUSUM	S		S		S		S	
CUSUM-sq	S		S		S		S	

***$p < 0.01$; **$p < 0.05$; and *$p < 0.10$

Source: Author's calculation

in Table 5. The effects of education variables and control variables remain consistent with the previous model findings as shown in Table 4. The robustness of the findings is confirmed through sensitivity analysis.

Conclusion and implications

Human capital is a by-product of education, and it serves as an input in the production function. Many advanced economies have moved from labor-intensive production methods to human capital intensive, which has transformed their economies and helped them achieve sustainable development. Following the footprint of many developed economies, emerging markets and developing economies started to develop human capital through education, technical training, and skill development programs. As a result, even the production techniques in the emerging economies are now becoming more environmentally friendly and emitting fewer carbons. Education provides the base for human capital development; however, investment in education infrastructure may hurt the environmental quality at the earlier stages and improve at the later stages. Empirics also have linked the positive impact of education on the environmental quality with the level of economic development, i.e., the positive effects of education on the environment are visible at a higher level of economic development.

China is an emerging economy growing fast, and the role of human capital is on a high in China's economic development. However, the role of different levels of education in the formation of EKC in China is underexplored. Therefore, the primary focus of this study is to evaluate the impact of various levels of education on the CO2 emissions in China. Moreover, the study also tested the EKC hypothesis for different levels of education and economic development. The analysis employed disaggregate and aggregate data for education that included enrollment at primary, secondary, and tertiary levels and the average year of schooling. For empirical analysis, we employed an error correction model and bounds testing approach to cointegration. The results of the study provided some useful information both in the short and long run. All the proxies of education positively impact CO2 emissions at the initial level both in the short and long run; however, when we take the square of these variables, the effects of education on CO2 emissions become negative. Similarly, the impact of economic growth on CO2 emissions is positive in the short and long run, and the square of economic growth on CO2 emissions is negative, supporting the EKC hypothesis. These findings imply that both education and economic growth follow an inverted U-shaped path while affecting the CO2 emissions, i.e., both education and economic growth degrades the environmental quality at the initial stages and improves at the later stages.

Based on the findings, we also provide some practical policy implications. Both education and development are interconnected, and both can affect the environmental quality via increased energy demand. Economic growth requires energy, which deteriorates the environmental quality at the initial stage due to energy-intensive infrastructure in the developing economies. Energy conservation policy may reduce CO2 emissions, but it can also deter China's economic growth because China heavily relies on non-renewable energy consumption for its economic development. This problem can be addressed by depending more on renewable energy projects and increasing the amount of renewable energy in the total energy mix. On the other side, an increase in educational infrastructure also pushes the energy demand upward, which may deteriorate the environmental quality at the initial stages. Energy is an essential demand of educational institutions; therefore, a prudent energy policy is required to improve energy performance and efficiency in educational institutions. In this regard, an energy policy should mainly focus on evaluating energy performance and conservation, attaining decreases in fossil fuel expenses, investing more in renewable energy projects, and installing clean and green energy sources for educational institutions and projects.

Based on limitations, the study proposes some future directions. Firstly, this research is done only for China; similar research can be replicated for other developed and developing countries. Secondly, this study gauged the symmetric association between educational attainment and EKC; in the future, an asymmetric association between educational attainment and EKC can also be estimated. In the future, a similar study can be conducted for provincial and regional levels of China.

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

Declarations

Ethics approval Not applicable.

Consent to participate I am free to contact any of the people involved in the research to seek further clarification and information.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

Ahmed Z, Zafar MW, Ali S (2020) Linking urbanization, human capital, and the ecological footprint in G7 countries: an empirical analysis. Sustain Cities Soc 55:102064

Aslam B, Hu J, Majeed MT, Lib Z, Ullah S (2021) Asymmetric macroeconomic determinants of CO 2 emission in China and policy approaches. Environ Sci Pollut Res 1–14

Balaguer J, Cantavella M (2018) The role of education in the environmental Kuznets curve Evidence from Australian Data. Energy Econ 70:289–296

Bangay C (2016) Protecting the future: The role of school education in sustainable development–an Indian case study. Int J Dev Educ Glob Learn 8(1):5–19

Bano S, Zhao Y, Ahmad A, Wang S, Liu Y (2018) Identifying the impacts of human capital on carbon emissions in Pakistan. J Clean Prod 183:1082–1092

Caird S, Lane A, Swithenby E, Roy R, Potter S (2015) Design of higher education teaching models and carbon impacts. Int J Sustain Higher Educ

Çakar ND, Gedikli A, Erdoğan S, Yıldırım DÇ (2021) Exploring the nexus between human capital and environmental degradation: the case of EU countries. J Environ Manag 295:113057

Dauda L, Long X, Mensah CN, Salman M, Boamah KB, Ampon-Wireko S, Dogbe CSK (2021) Innovation, trade openness and CO2 emissions in selected countries in Africa. J Clean Prod 281:125143

Duarte R, Mainar A, Sánchez-Chóliz J (2012) Social groups and CO2 emissions in Spanish households. Energy Policy 44:441–450

Grossman GM, Krueger AB (1995) Economic growth and the environment. Q J Econ 110(2):353–377

Hamid I, Shabbir A, Murshed M, Jena PK, Sha N, Alam MN (2021) The roles of foreign direct investments, economic growth, and capital investments in decarbonizing the economy of Oman. Environ Sci Pollut Res 1–17

Hamid I, Jena PK, Mukhopdhyay D (2020) Should China prefer more foreign direct investment inflows to environmental change? J Publ Aff 1–18

Inglesi-Lotz R, Morales LDDC (2017) The effect of education on a country's energy consumption: evidence from developed and developing countries. ERSA work pap, 678

Isik C, Ongan S, Ozdemir D, Ahmad M, Irfan M, Alvarado R, Ongan A (2021) The increases and decreases of the environment Kuznets curve (EKC) for 8 OECD countries. Environ Sci Pollut Res 28(22):28535–28543

Jafri MAH, Abbas S, Abbas SMY, Ullah S (2021) Caring for the environment: measuring the dynamic impact of remittances and FDI on CO2 emissions in China. Environ Sci Pollut Res 1–9

Jan A, Xin-Gang Z, Ahmad M, Irfan M, Ali S (2021) Do economic openness and electricity consumption matter for environmental deterioration: silver bullet or a stake? Environ Sci Pollut Res 1–16

Jian L, Sohail MT, Ullah S, Majeed MT (2021) Examining the role of non-economic factors in energy consumption and CO2 emissions in China: policy options for the green economy. Environ Sci Pollut Res 1–10

Jinru L, Changbiao Z, Ahmad B, Irfan M, Nazir R (2021) How do green financing and green logistics affect the circular economy in the pandemic situation: key mediating role of sustainable production. Econ Res-Ekon Istraživanja 1–21

Khan M (2020) CO2 emissions and sustainable economic development: new evidence on the role of human capital. Sustain Dev 28(5):1279–1288

Khan Z, Ali S, Dong K, Li RYM (2021) How does fiscal decentralization affect CO2 emissions? The roles of institutions and human capital. Energy Econ 94:105060

Khattak SI, Ahmad M, Khan ZU, Khan A (2020) Exploring the impact of innovation, renewable energy consumption, and income on CO2 emissions: new evidence from the BRICS economies. Environ Sci Pollut Res 27(12):13866–13881

Lei W, Ozturk I, Muhammad H, Ullah S (2021) On the asymmetric effects of financial deepening on renewable and non-renewable energy consumption: insights from China. Econ Res-Ekon Istraživanja 1–18

Li H, Khattak SI, Ahmad M (2021a) Measuring the impact of higher education on environmental pollution: new evidence from thirty provinces in China. Environ Ecol Stat 28(1):187–217

Li S, Zhou C (2019) What are the impacts of demographic structure on CO2 emissions? A regional analysis in China via heterogeneous panel estimates. Sci Total Environ 650:2021–2031

Li X, Ullah S (2021) Caring for the environment: how CO2 emissions respond to human capital in BRICS economies? Environ Sci Pollut Res 1–11

Li Y, Yang X, Ran Q, Wu H, Irfan M, Ahmad M (2021b) Energy structure, digital economy, and carbon emissions: evidence from China. Environ Scie Pollut Res 1–24

Lin X, Zhao Y, Ahmad M, Ahmed Z, Rjoub H, Adebayo TS (2021) Linking innovative human capital, economic growth, and CO2 emissions: an empirical study based on Chinese provincial panel data. Int J Environ Res Public Health 18(16):8503

Mahalik MK, Mallick H, Padhan H (2021) Do educational levels influence the environmental quality? The role of renewable and non-renewable energy demand in selected BRICS countries with a new policy perspective. Renewable Energy 164:419–432

Mahmood N, Wang Z, Hassan ST (2019) Renewable energy, economic growth, human capital, and CO 2 emission: an empirical analysis. Environ Sci Pollut Res 26(20):20619–20630

Mujtaba A, Jena PK (2021) Analyzing asymmetric impact of economic growth, energy use, FDI inflows and oil prices on co2 emissions through NARDL approach. Environ Sci Pollut Res 28(24):30873–30886. https://doi.org/10.1007/s11356-021-12660-z

Mujtaba A, Jena PK, Joshi DPP (2021) Growth and determinants of CO2 emissions: evidence from selected Asian emerging economies. Environ Sci Pollut Res 28(29):39357–39369

Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Appl Economet 16(3):289–326

Rahman MM, Nepal R, Alam K (2021) Impacts of human capital, exports, economic growth and energy consumption on CO2 emissions of a cross-sectionally dependent panel: Evidence from the newly industrialized countries (NICs). Environ Sci Policy 121:24–36

Sarwar S, Shahzad U, Chang D, Tang B (2019) Economic and non-economic sector reforms in carbon mitigation: empirical evidence from Chinese provinces. Struct Chang Econ Dyn 49:146–154

Shen K, Feng W, Cai Y (2018) A benevolent state against an unjust society? Inequalities in public transfers in China. Chin Sociol Rev 50(2):137–162

Sippel M, Meyer D, Scholliers N (2018) What about greenhouse gas emissions from students? An analysis of lifestyle and carbon footprints at the University of Applied Science in Konstanz, Germany. Carbon Manag 9(2):201–211

Sohail S, Ullah S, Javid AY (2021) Fiscal decentralization, institutional quality, and government size: an asymmetry analysis for Asian economies. Transl Corp Rev 10:1–15

Subramaniam Y, Masron TA (2020) Education, methane emission and poverty in developing countries. J Environ Econ Policy 9(3):355–369

Tiwari S, Paltasingh KR, Jena PK (2020) Caste-class association and school participation in Uttar Pradesh, India: evidence from NSSO data. Int J Educ Dev 79:1–9

Uddin MM (2014) Causal relationship between education, carbon dioxide CO2 emission and economic growth in Bangladesh. IOSR J Human Soc Sci (IOSR-JHSS) 19:60–67
Ullah S, Ozturk I, Majeed MT, Ahmad W (2021) Do technological innovations have symmetric or asymmetric effects on environmental quality? Evidence from Pakistan. J Clean Prod 316:128239
Ullah S, Ozturk I, Usman A, Majeed MT, Akhtar P (2020) On the asymmetric effects of premature deindustrialization on CO2 emissions: evidence from Pakistan. Environ Sci Pollut Res 27(12):13692–13702
Usman A, Bahmani-Oskoee M, Anwar S, Ullah S (2021a) Is there J-curve effect in the trade between Pakistan and United Kingdom? Asymmetric evidence from industry level data. Singap Econ Rev 1–21
Usman A, Ozturk I, Hassan A, Zafar SM, Ullah S (2021b) The effect of ICT on energy consumption and economic growth in South Asian economies: an empirical analysis. Telemat Inf 58:101537
Wang J, Xu Y (2021) Internet usage, human capital and CO2 emissions: A global perspective. Sustainability 13(15):8268
Wang X, Shao Q (2019) Non-linear effects of heterogeneous environmental regulations on green growth in G20 countries: evidence from panel threshold regression. Sci Total Environ 660:1346–1354
Yan G, Peng Y, Hao Y, Irfan M, Wu H (2021) Household head's educational level and household education expenditure in China: the mediating effect of social class identification. Int J Educ Dev 83:102400
Yao Y, Ivanovski K, Inekwe J, Smyth R (2020) Human capital and CO2 emissions in the long run. Energy Econ 91:104907
Yin Y, Xiong X, Ullah S, Sohail S (2021) Examining the asymmetric socioeconomic determinants of CO2 emissions in China: challenges and policy implications. Environ Sci Pollut Res 1–11
Zafar MW, Saleem MM, Destek MA, Caglar AE (2021) The dynamic linkage between remittances, export diversification, education, renewable energy consumption, economic growth, and CO2 emissions in top remittance-receiving countries. Sustain Dev 1–11

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