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Research Article

Environmental Effects of China's Nuclear Energy within the Framework of Environmental Kuznets Curve and Pollution Haven Hypothesis

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Abstract
This study investigates the environmental sway of China's nuclear energy use in the perspective of the Environmental Kuznets Curve (EKC) and Pollution Haven Hypothesis (PHH) by using the time series data from 1993 to 2022. The study used an autoregressive distributed lag (ARDL) simulating method. One of the limitations of the study is the short range of the data although the ARDL method perfectly applicable for the dataset with a short range. The findings of empirical research support that the PHH does not apply to China, meaning that foreign direct investment significantly impacts environmental results. Moreover, empirical findings confirmed the helpful impact of nuclear energy in reducing pollutants. Furthermore, the outcome confirms the EKC theory in the Chinese context, suggesting that increasing economic expansion may decrease emission levels in the future. Higher economic growth and increased foreign investment in nuclear energy generation are expected to improve environmental excellence by decreasing carbon emissions.

Keywords: Climate change, nuclear energy, carbon emissions, EKC; PHH; sustainable development.

Introduction

China is confronted with considerable challenges when it appears to tackling the issue of rising emissions of CO_2, as evidenced by current study and reports [1]. Identifying strategies to mitigate pollution is crucial for promoting equitable development in the nation [2]. Nevertheless, foreign direct investment (FDI) has been instrumental in driving the growth of the global economy, thanks to the progress made in financial liberalization as well as the increasing disconnectedness of economies worldwide over the last three decades [3] which may be associated with environmental sustainability. As a result, many researchers have focused on investigating (PHH) to understand the relation among FDI with CO_2 emissions [4,5]. It has been noted in previous studies that developed nations tend to shift their harmful businesses to underdeveloped countries in order to take advantage of lower input costs, such as lower labor wages and energy expenses. Therefore, FDI can facilitate the transfer of cutting-edge technologies from one country to another, indicating to bigger investments in renewable energies [6]. China is one of the biggest FDI recipients. China's FDI inflow rose from $3.5 billion in 1990 to $344 billion in 2021 due to economic sector reforms [7]. However, the growing carbon emissions from China pose a significant threat to ecological sustainability and demand careful consideration. The main reason for China's failure to achieve its prevention target is the growing dependence on natural gas to support the industry. Fossil fuels contribute to the generation of atmospheric CO_2, leading to ecological damage and presenting a major obstacle to achieving long-term sustainability [8,9].

A shift towards utilizing green energy resources like hydrogen, and water, along with solar energy, is crucial for reducing emissions in manufacturing of electricity is being impacted by the rise in CO_2 emissions, which is causing health and safety issues [10-12]. Researchers are concerned about transitioning from polluting sources of energy to clean sources due to global warning's impact on climate change [13]. Clean energy is widely acknowledged as a viable solution to reduce emissions [14]. Renewable energy is more lucrative and has significant market opportunities [15]. The advancement of renewable energy sources promotes economic progress, ensures energy security, and reduces poverty [16]. Renewable sources encourage more environmentally friendly production methods and can help decrease the rising levels of carbon emissions [17]. Renewable and nuclear sources of energy have lower environmental impacts compared to petroleum, natural gas, and coal are examples of petroleum power sources [18]. Recently, nuclear power has become an exciting source of power—an option for reducing emissions [19]. Nuclear energy helps with environmental conservation and reduces reliance upon sources from other countries [20]. Nuclear power is crucial for tackling power supply concerns, environmental harm, and cutting pollutants [21]. Nuclear power is a major source of contamination by releasing emissions that include radioactive compounds and nuclear waste, which require proper management and disposal [22]. This investigation addresses the association including nuclear power as well as CO_2 emissions in China using the PHH paradigm to clarify the confusing connection.

This investigation adds to the standing frame of research through evaluating the effects of nuclear power in conjunction with FDI and economic growth within the setting of the PHH structure and EKC for China. Exploring China's PHH is important because industrialized nations may relocate their polluting businesses to China, potentially degrading environmental conditions. This research aims to investigate potential distinctions among the Chinese economy and other economies, mainly focusing on growing and broadening them in terms of how nuclear energy use impacts environmental quality. Furthermore, The ARDL method is handled to assess the short- and long-term ecological impacts of the chosen factors.

Literature Review

Energy performs a vital part through the production of services and goods and is a crucial driver of economic growth [23]. Energy is widely regarded in the literature as the primary factor influencing environmental contamination [24]. Countries worldwide are transitioning to cleaner energy sources due to their harmful environmental impacts. Nuclear energy has the potential to meet increasing energy needs and improve environmental conditions, while its environmental effects remain uncertain due to conflicting results in past research [20]. Opinions on the environmental effects of nuclear energy are divided in literature. Some research suggests that nuclear energy has environmental benefits. For instance, Azam et al. [25] Emphasized the noteworthy effect of nuclear energy generation in fostering environmental cleanliness, as evidenced by their findings about the ten nations with the most significant emissions of CO_2.

Furthermore, the ecological implications of nuclear energy in the top 10 nations consuming the most nuclear energy from 1990 to 2017 were evaluated by Sadiq et al. [26]. The result showed that decreasing carbon emissions is one way nuclear power can protect the environment. Jahanger et al. [27] used moment's quantile regression to study the effect of radiation regarding the production of carbon in leading nuclear-power nations based on data spanning 1990-2017. Atomic power provides a sustainable alternative regarding traditional fossil fuels since it reduces CO_2 emissions across all quantiles. The results also provide strong proof for the EKC postulate. Hassan et al. [28] observed the usage and production of nuclear power in BRICS countries had a substantial influence on mitigating air pollution. Saidi and Omri [29] exhibited the substantial influence of nuclear energy in lowering carbon emissions in various OECD nations.

Moreover, Piłatowska et al. [30] indicated that using nuclear power has a mitigating effect on CO_2 pollutants in Spain. Syed et al. [31] utilized the asymmetric ARDL approach to direct an evaluation the unequal consequences of nuclear power and economic development on India's carbon emissions between 1975 and 2018. The study found that using nuclear energy instead of fossil fuels led to lower CO_2 emissions. Located in India from 1970 to 2016, Ozgur et al. [32] explored the consequences of nuclear power deployment on the emission of CO_2 within India using the Fourier ARDL model in an effort to verify the EKC hypothesis. The result suggests that expanding the utilization of nuclear electricity is a prerequisite for attaining equitable and environmentally friendly progress, just like a policy objective.

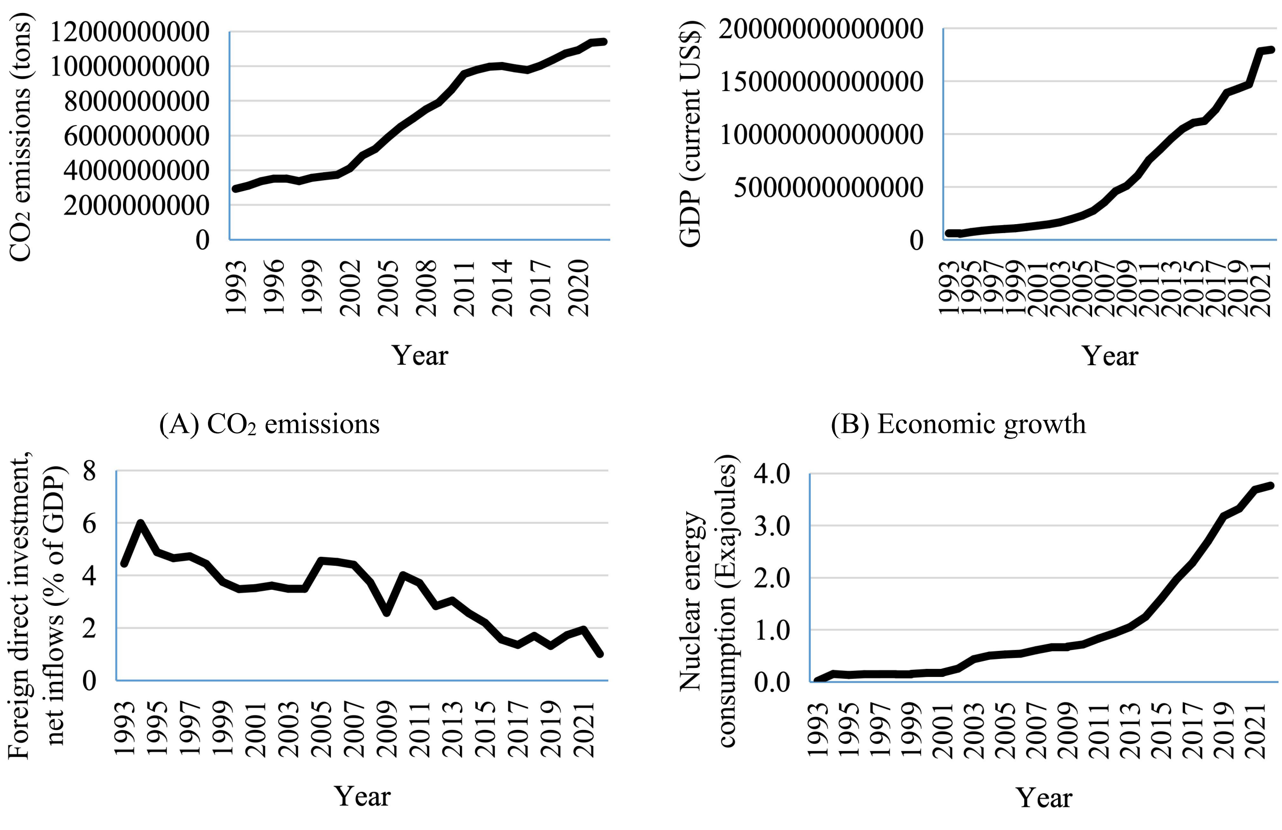
Kartal et al. [33] examined how switching to nuclear energy sources would affect CO_2 emissions in the United States. The result showed nuclear power has positive impacts on surroundings. Omri and Saadaoui [34] utilized the non-linear ARDL method to analyse the consequences of atomic fuel on France's CO_2 emissions from 1980 to 2020. The significance of the EKC presumed was also assessed. The most important finding was that using nuclear power in France helps to cut the country's carbon footprint. Zeraibi et al. [35] examined how nuclear power affects France's energy independence and carbon footprint. The ARDL model indicates that nuclear power helps lower energy risks while raising prices. Furthermore, the outcome of the research bestowed favor for the U-shaped EKC theory.

Dong et al. [36] carried out studies across China analyzing the impact of radiation on nature in comparison to Comparing petroleum and solar power usage from 1993 to 2016. The study validated EKC concept and discovered nuclear power had a beneficial impact on reducing pollution. Xie et al. [37] Executed an experiment across China using a parameter isolate works as well as determined the fact that atomic energy seems a more efficient alternative to petroleum and coal compared to green energy due to its greater capacity to reduce CO_2 emissions.

Prior research has identified a link among nuclear power and the release of carbon dioxide offering substantial data. Challenges in utilizing modeling techniques and variables have restricted the availability of well-structured and thorough evaluations. This study utilized sophisticated methods for assessing the time series data to investigate the association within nuclear energy and contaminations within the context of the EKC and PHH.

Methodology

The research project analyzed the consequence of nuclear power, economic expansion, along with FDI upon CO_2 emissions in China. The investigation employed an ARDL approach and Spanning compared to 1993 to 2022. The CO_2 emissions were gathered from Our World in Data. Nuclear energy data came from the Statistical Review of World Energy. FDI and GDP statistics came from the World Development Indicators. Figure 1 shows the annual trends of variables. To normalize data, variables were converted to natural logarithms.



(A) CO_2 emissions (B) Economic growth

(C) Foreign direct investment (D) Nuclear energy use

Figure 1. Annual trends of the variables.

Previous studies mainly concentrated on utilizing the EKC theory with nuclear energy to develop an empirical model, neglecting to explore more detailed model specifications. This study extends the traditional model of the relationship between nuclear energy, economy, and CO_2 emissions to incorporate the significance of FDI inside the PHH framework.

$$LC_t = \tau_0 + \tau_1 LY_t + \tau_2 LF_t + \tau_3 LN_t + \varepsilon_t \quad (1)$$

Where LC_t, LY_t, LF_t, and LN_t are the logarithmic form of CO_2 emissions, economic growth, FDI, and nuclear energy consumption at time t.

However, incorporating non-stationary variables in regression models may result in imprecise results. It is important to ensure that all considerations are stationary prior to making any modifications. In this investigation, three unit root tests were utilized to assess the stationarity of the data set. These tests include the Augmented Dickey-Fuller (ADF) test [38], the Dickey-Fuller generalized least squares (DF-GLS) test [39], and the Phillips-Perron (P-P) test [40].

This study employed the ARDL method [41] to examine the correlation among each variable. The ARDL method provides numerous benefits compared to alternative cointegration approaches, rendering it a widely preferred option for examining long-term relationships among variables in econometrics. An important benefit of this is its versatility and suitability for both small and large sample sizes. Contrary to conventional cointegration techniques like the Engle-Granger two-step procedure or Johansen's approach, which necessitate a relatively large dataset for accurate estimation, the ARDL method can adeptly handle small sample sizes without compromising statistical power or efficiency [42-44]. This feature is especially beneficial for researchers who have limited access to data or are studying rare phenomena in specialised fields with a scarcity of large datasets [45-47]. In addition, the ARDL approach is capable of handling mixed-order integration among variables, enabling the examination of cointegration relationships between variables that have varying degrees of integration. The ability to adapt is especially beneficial when working with variables that demonstrate varying levels of persistence or trends over time, a common occurrence in economic and financial data.

To verify whether the variables are consistently associated, we used the ARDL bounds test. We reject the null hypothesis (H_0) suggesting no co-integration among the study variables if the F test result reaches the maximum essential threshold, following the critical value table by Pesaran et al. [41]. Conversely, a biassed result is shown if the F test value is inside the critical boundaries. Based on our findings, it seems that the variables are not cointegrated, supporting H_0. The computed F-test result is fortunate in that it is less than the lower critical threshold. When there is a long-term correlation linking the variables under study, the long-term coefficient may also be determined. Below you will find the long-run estimate model's formula:

$$\Delta LC_t = \tau_0 + \tau_1 LC_{t-1} + \tau_2 LY_t + \tau_3 LF_t + \tau_4 LN_t + \sum_{i=1}^{q} \alpha_1 \Delta LC_{t-i} + \sum_{i=1}^{q} \alpha_2 \Delta LY_{t-i} + \sum_{i=1}^{q} \alpha_3 \Delta LF_{t-i} + \sum_{i=1}^{q} \alpha_4 \Delta LN_{t-i} + \varepsilon_t \quad (2)$$

When a long-term correlation within the research parameters is identified, a likelihood for the short-term model is comprised. Equation (4) signifies the short-run error correction model (ECM).

$$\Delta LC_t = \tau_0 + \tau_1 LC_{t-1} + \tau_2 LY_t + \tau_3 LF_t + \tau_4 LN_t + \sum_{i=1}^{q} \alpha_1 \Delta LC_{t-i} + \sum_{i=1}^{q} \alpha_2 \Delta LY_{t-i} + \sum_{i=1}^{q} \alpha_3 \Delta LF_{t-i} + \sum_{i=1}^{q} \alpha_4 \Delta LN_{t-i} + \theta ECM_{t-1} + \varepsilon_t \quad (3)$$

Where θ, the error correction coefficient, is a crucial component of the estimated model. The provided value demonstrates the factor for adjustment speediness, flashing the rate at which the series touches to a long-term equilibrium.

Results and Discussion

The statistical results of the variables are shown in Table 1. The results exhibit that the variables have a negative skewness. The low sleekness values suggest that the majority of those factors follow a normal distribution. All the series exhibit platykurtic properties, with kurtosis estimates below 3. Based on the Jarque-Bera probability, it ensures that all variables follow a normal distribution.

Table 1. Descriptive and correlation statistics

Variables	LC	LY	LF	LN
Mean	22.57	28.91	1.10	-0.56
Median	22.70	29.02	1.25	-0.45
Maximum	23.15	30.51	1.78	1.32
Minimum	21.79	27.05	0.09	-4.11
Skewness	-0.28	-0.10	-0.79	-0.46
Kurtosis	1.43	1.51	2.59	2.01
Jarque-Bera	3.48	2.82	3.40	1.09
Probability	0.17	0.24	0.18	0.57

Figure 2 shows the correlation between the variables. LC, LY, and LN have a positive correlation, as indicated by the correlation matrix. In contrast, LF shows a negative correlation with other variables.

Table 2. Correlation analysis

	LC	LY	LF	LN
LC	1.00			
LY	0.98	1.00		
LF	-0.75	-0.82	1.00	
LN	0.93	0.94	-0.80	1.00

The unit root testing results are shown in Table 3. As per the results, it was found that the variables were not initially stationary. However, they converted stationary when their first differences were taken into account in all three unit root tests. By utilizing the outcome of the unit root tests, we can effectively analyze them within the ARDL framework.

Table 3. Results of unit root testing.

Variables	ADF		DF-GLS		P-P	
	Log levels	Log first difference	Log levels	Log first difference	Log levels	Log first difference
LC	-1.14	-3.61***	-0.38	-3.65***	-1.16	-3.55***
LY	-1.09	-3.41***	-0.63	-3.41***	-0.71	-5.12***
LF	-0.33	-6.12***	-0.33	-5.57***	-0.04	-6.26***
LN	-0.23	-3.83***	-0.29	-3.29***	-0.27	-9.11***

***P<0.01

The investigation employed the ARD-bound testing system to conduct a thorough and clear long-term co-integration analysis among the variables (Table 5). The conclusion suggests the occurrence of co-integration, indicating a long-term connection among variables. The F statistic (7.31) for this model supports the claim, as it surpasses the upper critical values.

Table 4. Results of ARDL bounds test

Test statistic	Value	Significance at	I(0)	I(1)
F-statistic	7.31	10%	2.37	3.20
K	3	5%	2.79	3.67
		2.5%	3.15	4.08
		1%	3.65	4.66

After determining Cointegration of the variables have been confirmed, the next focus is to examine the long- and short-term correlations linking GDP, nuclear energy, FDI, and emission of CO_2. The results of the ARDL estimation, as illustrated in Table 4, provide insight into the long-term and short-term relationships among the key variables being examined. The notable and highly significant coefficients associated with GDP emphasize the detrimental consequences of economic growth on environmental pollution. More precisely, a 1% rise in GDP leads to a significant 0.82% rise in CO_2 emissions in the long run, which further escalates to a 1.04% expansion in the short run.

Furthermore, the anticipated coefficients related to nuclear energy exhibit a negative trend and hold statistical significance. A mere 1% escalation in nuclear energy utilization is projected to yield a substantial reduction of 0.32% in CO_2 emissions over the long term, complemented by a 0.22% reduction in the short term. These findings underscore nuclear energy's potential as a viable option for curbing carbon emissions and mitigating environmental impact. In contrast, the long-term coefficient associated with FDI displays a negative correlation, while its short-term counterpart manifests as positive. This signifies that a 1% surge in FDI initially corresponds to a 0.43% uptick in CO_2 emissions in the near term. However, over the long term, this liaison transitions, following in a notable 0.08% reduction in emissions. This shift can be ascribed to the transfer of clean technology facilitated by FDI, particularly in regions like China, thus, assisting in the overall decline of emissions. These findings underscore the complex interplay between foreign investment, technological transfer, and environmental outcomes, emphasizing the need for nuanced policy approaches to ensure sustainable development.

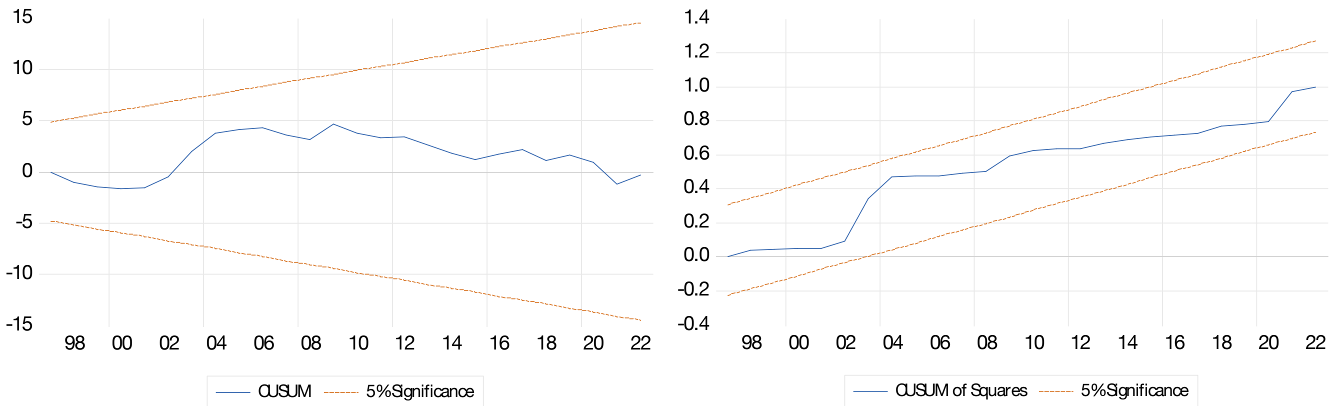
Table 5. ARDL long and short-run results

Variables	Long-run			Short-run		
	Coefficient	t-Statistic	p-value	Coefficient	t-Statistic	p-value
LY	0.82***	3.62	0.00	1.04***	3.39	0.00
LN	-0.32***	-4.77	0.00	-0.22***	-4.83	0.00
LF	-0.08***	-3.61	0.00	0.43***	3.21	0.00
C	16.04	1.58	0.13	-	-	-
ECM (-1)	-	-	-	-0.57***	-3.80	0.00
R^2	0.99					
Adjusted R^2	0.99					

***P<0.01

At the 1% level of significance, the determined ECM shows a negative trend, above the significance threshold. Agricultural innovations, trade openness, economic progression, and the incorporation of renewable energy resources are some of the pathways that seem to be quickly resolving current year's changes from long-term equilibrium at a pace of 57%. In addition, the long-run estimate has an R^2 and adjusted R^2 value of 0.99, showing that the regression model is quite accurate. These numbers show that the model is strong at capturing the system dynamics; more specifically, that the factors that are independent defend 98% of the modification in the fluctuations of the dependent variable.

There were two assessments performed to determine the model's steadfastness: cumulative sum (CUSUM) with cumulative sum of squares (CUSUMSQ). Figure 2 shows the recursive regression residuals from which these analyses were produced. Since the statistical line stays inside the crucial bounds at a significance level of 5%, we can confirm that the computed ARDL coefficients are stable.



(A) CUSUM plot (B) CUSUMSQ plot

Figure 2. The results of CUSUM and CUSUMSQ tests

To further validate the dependability of the ARDL model used in this research, this inquiry also performed extra diagnostic tests included in Table 6. The diagnostic analysis confirms that the model parameters were appropriately set, and that the residuals follow a normal distribution. Also, no serial correlation nor heteroscedasticity are seen.

Table 6. The results of diagnostic tests

Diagnostic tests	Coefficient	p-value	Decision
Jarque-Bera test	1.28	0.53	Normal residual distribution
Breusch-Godfrey LM test	1.76	0.18	No serial correlation exists
Breusch-Pagan-Godfrey test	0.21	0.89	No heteroscedasticity exists
Ramsey RESET test	1.82	0.18	The model is appropriately specified

China's growing economy encounters a favorable impact on emissions in the short and long run. The procedure framework about the effects of GDP in the short term can be expanded to encompass the long term. The results of the investigation support previous inquiries on the association among GDP growth and CO_2 emissions in China. For example, Cheng et al. [48], Kongkuah et al. [49], Yilanci and Pata [50], and Zhang et al. [51]. The research reveals that the coefficient for GDP indicating long-term effect (0.82) is lower than the coefficient for short-term effect (1.04). When China experiences prolonged economic growth, there is a possibility of reduced ecological contamination. The outcomes of the EKC theory are demonstrated in China, suggesting that the country's future economic advancement could decrease CO_2 emissions. The outcomes presented in this study are backed by earlier research that provides evidence supporting the EKC theory regarding CO_2 emissions in China [52-54]. Throughout the initial stages of economic growth, there is a noticeable rise in the emission of CO_2 into the planet, leading to a decline in general ecological health. However, this trend reverses once a specific level of economic advancement is achieved. Increased prosperity leads to economic expansion, contributing to environmental improvement. Following a reversed U-shaped pattern, this discovery suggests a non-linear correlation between GDP and CO_2 emissions. Utilizing emission reduction technology and economic expansion has been shown to significantly improve environmental quality by reducing carbon emissions [55-58]. Continued economic growth helps reduce emissions and is decisive for addressing climate change.

Nuclear power significantly contributes to reducing carbon emissions, making it environmentally advantageous. Research supports the assertion that China's nuclear activities produce minimal CO_2 emissions, suggesting that transitioning to nuclear power might assist in reducing pollution [36,37]. China needs diversification of energy sources. In China, atomic power is an energy provider that produces little carbon emissions. However, it produces electricity that requires significant attention to safety concerns [59]. Proper handling of radioactive waste and the construction of the nuclear plant must be done cautiously to prevent potential incidents that could harm the environment and public health [60]. Implementing revolutionizing the power industry is a prudent decision to decrease emissions. The findings of this investigation confirmed the conclusions of previous research [25-37].

Various research studies regarding the correlation among nuclear power and CO_2 emissions have yielded conflicting results due to inadequate management of nuclear waste disposal.
FDI has a notable and beneficial environmental impact, suggesting it adds to pollution in the near term. The current study discovered that the environmental effects of FDI differ between short and long-term frames. Environmental planning requires long-term consideration based on the outcome of FDI's clean role [61]. The adverse long-term effect of FDI on emissions supports concerns about the unrestricted movement of global commerce and investment. This is the predominant methodological impact of FDI on economies of scale, reflecting a country's level of improvement. Advanced technology enhances ecological quality by producing clean items through the method impact. When FDI increases wealth, emission intensity may decrease since the environmental condition would be better. China benefits from improved environmental quality due to the favorable impact of FDI by implementing cleaner industry technology. The reason is the strict environmental restrictions and laws in China. Research findings suggest that the pollution haven theory does not apply to China, as FDI contributes significantly to environmental sustainability by decreasing China's emissions. Previous studies corroborate the present study's findings [62-66].

Conclusion

This study analyzed exploring the implications regarding FDI of nuclear power upon carbon emissions throughout China while considering the consequences of economic expansion. The EKC and PHH are analyzed with the ARDL simulation tactic operating data throughout 1993-2022. The bound testing approach verified the actuality of co-integration across the specified variables in the study. The ARDL findings indicate no presence of the PHH, implying that FDI enhances China's regulations on ecology by decreasing carbon emissions over time. Solar power is a renewable power origin that minimizes pollution. The conclusion confirms the EKC hypothesis, showing that increasing economic expansion could decrease China's emission levels.
The results indicate that several regulations need to be established to foster and draw more foreign investment. Introducing cleaner technologies along with trade items could positively impact the environment. Increasing the proportion of nuclear electricity in China's power combination will facilitate the country's shift to a carbon-neutral economy. Moreover, utilizing nuclear energy for electricity generation is essential for reducing dependence on conventional power sources alongside imported energy. Efforts to promote energy efficiency are vital in tackling climate change.
The Chinese administration ought to increase foreign investment in its nuclear power sector, emphasizing long-term strategies to enhance energy production. The advancement in nuclear power will undoubtedly boost the nation's reputation and the importance of alternative power resources, fostering revenue generation while encouraging societal and beneficial environmental advancements. Atomic power is an affordable energy option that improves the security of supply and has a beneficial impact on the planet by decreasing airborne pollutants and minimizing damage to the ozone layer. It may appear attractive for financial, ecological, and social reasons.

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Authors contributions: Asif Raihan contributed a key role in formulating and designing the study. Asif Raihan, Shakil Ahmad, Junaid Rahman, and Tipon Tanchangya conducted material preparation, data collection, and analysis. Asif Raihan took charge of the initial draft of the manuscript, while Mohammad Ridwan provided valuable insights on earlier versions. The final manuscript was read and approved by all authors.
Data availability statement: The data on CO_2 emissions were collected from the Our World in Data (OWD) dataset, while the data on nuclear energy was collected from the Statistical Review of World Energy. Additionally, the data on FDI and GDP were retrieved from the World Development Indicators (WDI).

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