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The Green Engine of Growth: Assessing the Influence of Renewable Energy Consumption and Environmental Policy on China's Economic Sustainability

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Abstract: Utilizing Fourier autoregressive distributed lag and Fourier Toda–Yamamoto causality methodologies, this research assesses the effects that renewable energy consumption and environmental policy had on the economic sustainability of China from 1991 to 2022. Our findings highlight the positive impacts of renewable energy use and stringent environmental policies on China's economic growth, while also pinpointing the supportive roles played by foreign direct investment, trade openness, and financial sector evolution in fostering a sustainable economic environment. Conversely, a reliance on fossil fuels emerges as a significant barrier to sustainability. Causality tests confirm the essential roles of renewable energy and environmental policies in advancing China's economic sustainability. This study underscores the critical need for integrating sustainable energy and environmental strategies within China's economic development framework, advocating for a holistic policy approach that balances economic growth with environmental conservation. This research underscores the imperative for a sustainability-centered strategy for China's economic advancement.

Keywords: renewable energy consumption; environmental policy; economic sustainability; Fourier Toda–Yamamoto causality test; Fourier autoregressive distributed lag methodology

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1. Introduction

As the world grapples with escalating environmental challenges, the critical role of renewable energy adoption and the implementation of strict environmental policies in securing economic sustainability gains broader recognition. China, a significant source of global greenhouse gas emissions, is at the forefront of this crucial transition. The shift towards an environmentally sustainable economic framework in China is motivated by global environmental commitments and the essential need for domestic economic durability (Yang and Zhan [1] and Yang et al. [2]). This backdrop lays the groundwork for a detailed examination of the influence that renewable energy projects and environmental policy reforms have on guiding China towards sustainable economic growth, positioning it as a leader in merging economic development with environmental conservation. In the face of swift industrialization, China faces formidable environmental obstacles, necessitating an urgent reevaluation of its growth strategies. In response, the Chinese government has unveiled an ambitious agenda focused on embracing renewable energy sources, such as wind, solar, and hydropower, and enforcing strict environmental policies (Wu et al. [3] and Zhao et al. [4]). This deliberate pivot aims to sever the link between economic progress and environmental harm, aspiring to forge an economic structure that is resilient and sustainable in the face of future environmental adversities.

Recent studies, including those by Fang [5], Chen et al. [6], and Abbas et al. [7], which explore the economic benefits of renewable energy investments, along with analyses by Zhang et al. [8], Jiakui et al. [9], and Dzwigol et al. [10] on the productivity impacts of environmental regulations, provide empirical support for the positive link between sustainability measures and economic performance. These findings counter the traditional dichotomy between environmental stewardship and economic growth, suggesting that green technologies and policies can actually bolster economic sustainability. Additionally, research by Xiao et al. [11], Lu and Yan [12], and Wang et al. [13] emphasizes the importance of foreign direct investment and trade openness in facilitating China's green transition, highlighting the roles of international collaboration and market integration in sustainable development. Nonetheless, China's ongoing dependence on fossil fuels poses a significant challenge to achieving full economic sustainability, as evidenced by studies like those of Sun [14], Ren et al. [15], Yang et al. [16], and Jiang et al. [17], which associate fossil fuel consumption with environmental and economic risks. This study, using advanced econometric methods to analyze data from 1991 to 2022, aims to dissect the complex interactions between renewable energy use, environmental policy rigor, foreign direct investment, trade liberalization, financial sector growth, and their combined effects on China's economic sustainability. By offering a nuanced exploration of the "Green Engine of Growth," this research not only enriches the scholarly dialogue on sustainable development but also provides actionable insights that are useful for policy formulation in China and beyond, advocating for a strategy that harmonizes economic advancement with environmental conservation.

Drawing from the research context, this study applies Fourier autoregressive distributed lag (The Fourier autoregressive distributed lag technique represents a sophisticated econometric method designed to analyze the dynamic relationships between time-series variables over short and long terms. This approach integrates the traditional autoregressive distributed lag model with Fourier series to enhance the model's ability to capture non-linear trends and structural breaks within data. The incorporation of the Fourier series allows for a more flexible functional form, enabling the model to adapt to and accurately represent cyclical and seasonal patterns as well as abrupt changes in the underlying processes of the variables under study. By accommodating these complexities, the Fourier autoregressive distributed lag technique provides a nuanced understanding of the interplay between dependent and independent variables, making it an invaluable tool for economists and researchers analyzing time-series data with potential non-linear characteristics and structural shifts) and Fourier Toda–Yamamoto causality (The Fourier-Toda–Yamamoto causality technique is an advanced econometric method designed to assess causality relationships between time-series variables, incorporating the flexibility to account for non-linear patterns and structural breaks. This methodology builds on the Toda–Yamamoto causality framework by integrating Fourier functions, enabling the detection of causality amidst complex economic phenomena characterized by cyclical behaviors and abrupt shifts. The technique's inclusion of Fourier series allows it to model and adjust for these non-linear dynamics, providing a more accurate and comprehensive analysis of causality beyond the linear assumptions of traditional methods. This approach is particularly useful in empirical research where underlying economic relationships may undergo significant changes over time or exhibit periodic fluctuations. By employing the Fourier-Toda–Yamamoto causality technique, researchers can uncover nuanced causal links that might remain obscured under standard linear causality tests, thus offering valuable insights into the temporal dynamics influencing economic variables) techniques to examine the influence of renewable energy consumption and environmental policy on China's economic sustainability over the period of 1991–2022. The analysis reveals that the adoption of renewable energy and the enforcement of rigorous environmental regulations significantly contribute to China's economic expansion. Additionally, our findings highlight the beneficial impact of foreign direct investment, the opening of trade, and the expansion of the financial sector, which are crucial elements aiding China's quest for an economically sustainable future. In contrast, dependency on fossil fuels is identified as a major obstacle to achieving sustainability. Our causality analysis further validates the pivotal role that renewable energy consumption and environmental policy play in enhancing China's economic sustainability. This investigation highlights the necessity of incorporating strategies focused on sustainable energy and environmental preservation into China's broader economic growth plans, calling for a comprehensive policy framework that ensures a balance between economic development and environmental protection. Our findings emphasize the crucial need to adopt strategies centered around sustainability to drive China's economic progress forward.

This study makes four significant contributions to the existing body of knowledge on China's sustainable development, each underscored by a comparison with the relevant literature. Firstly, it empirically substantiates the positive influence of renewable energy consumption on China's economic sustainability, advancing prior studies by Xu et al. [18], Long et al. [19], and Wang et al. [20], who highlighted renewable energy's benefits without exploring its enduring economic sustainability impacts. Secondly, this investigation underscores the essentiality of stringent environmental policies, providing empirical backing to the theoretical propositions of Yan et al. [21], Jin and Wang [22], Wang and Zhang [23], and Wu et al. [24], who postulated but did not quantitatively demonstrate the linkage between policy rigor and sustainability achievements. Thirdly, this study elucidates the composite beneficial effects of foreign direct investment, trade openness, and financial sector growth on sustainable economic progression, refining the isolated factor analyses conducted by Sun et al. [25] and Bian et al. [26]. Fourthly, it offers a nuanced critique of fossil fuel reliance, augmenting the pollution-centric analyses of Lei et al. [27], Ji et al. [28], and Butt et al. [29] with a broader examination of economic sustainability implications. Together, these insights not only bridge significant gaps by furnishing robust empirical evidence on the diverse determinants of economic sustainability in China but also highlight the imperative for a cohesive policy schema. This schema should integrate renewable energy, environmental policy, strategic investments, and sectoral advancements within a framework prioritizing sustainable growth alongside ecological preservation.

This manuscript is structured as follows: Section 2 conducts a critical review of the literature, assessing both seminal and contemporary studies relevant to our topic. In Section 3, we detail the research methodology, including variable selection and the construction of the model framework. Section 4 delves into the empirical results obtained from our analysis. This paper concludes with Section 5, summarizing the main findings, offering policy recommendations, and suggesting directions for future research within this field.

2. Literature Review

In reevaluating the discourse on the interplay between renewable energy consumption and economic sustainability, an appropriate and rational critique emerges, revealing not only a consensus on the positive impacts but also illuminating the methodological and analytical diversities within existing research. This domain, rich in varied perspectives and empirical evidence, posits renewable energy as a cornerstone of sustainable economic growth, underscored by its reduced environmental footprint and sustainability credentials. Ebhota and Jen [30], Rehman et al. [31], and Liu et al. [32] position wind and solar energy as pivotal for bypassing the environmental degradation inherent in fossil fuel usage, driving home the role of renewables in sustainable economic advancement. This argument finds further support in the works of Sweeney et al. [33], Seck et al. [34], and Chen et al. [35], who delve into the economic benefits of renewable energy's cost stability. However, the transition to renewable energy, despite its merits, is fraught with economic and logistical hurdles, as evidenced by Hoang et al. [36], Koasidis et al. [37], and Ofélia de Queiroz et al. [38], highlighting the challenges of substantial upfront investments and the potential for labor market upheavals. In contrast, rapid technological advancements in the renewable sector, as noted by Cantarero [39], Denholm et al. [40], and Asghar et al. [41], have begun to address feasibility concerns, enhancing efficiency while reducing costs. The critical role of supportive policies in facilitating this energy shift is irrefutable, with Qamruzzaman and Karim [38], Ahmad et al. [39], and Yue et al. [40] underscoring the necessity of incentives for renewable energy adoption to realize its economic benefits. The global narrative, as painted by Lu et al. [42], Afshan et al. [43], and Bashir et al. [44], showcases the success of nations with stringent environmental policies in embedding renewable energy within their economic paradigms, thereby enhancing sustainability. Empirical validations of the positive correlation between renewable energy investment and economic growth are provided by Przychodzen and Przychodzen [45], Anton and Nucu [46], and Belaïd et al. [47], designating renewable energy as a lever for economic expansion in developing contexts. Yet, the sector-specific and regional variability in renewable energy's impact, as critiqued by Chou et al. [48], calls for tailored strategies to navigate these differences. The role of renewable energy in driving technological innovation and economic diversification, thereby bolstering sustainability, is evidenced by Ahmed et al. [49], Fang et al. [50], and Wen et al. [51]. Further, the renewable sector's capacity for job creation, highlighted by Kumar and Majid [52], Mutezo and Mulopo [53], and Heffron et al. [54], underscores its contribution to economic resilience. However, this narrative is complicated by concerns around inefficiencies and increased operational costs in the absence of adequate energy management and grid integration strategies, as pointed out by Alam et al. [55], Al-Shetwi et al. [56], and Sinsel et al. [57]. Nonetheless, the overarching sentiment, as echoed by Kabeyi and Olanrewaju [58] and Androniceanu and Sabie [59], is that the enduring benefits of renewable energy—from environmental preservation to bolstering economic stability and growth—vastly outweigh the transitional challenges. In summation, the scholarly dialogue robustly affirms renewable energy's instrumental role in fostering economic sustainability, emphasizing the imperative for technological innovation, strategic policy implementation, and sector-specific adjustments. Despite the inherent complexities of transitioning to renewable energy systems, the collective academic stance ardently advocates for its critical significance in securing a sustainable economic future, calling for a deeper analytical engagement with the diversity of findings and methodological approaches within this domain.

The debate surrounding the interplay between environmental policy and economic sustainability is multifaceted, reflecting a spectrum of scholarly opinions on whether regulatory frameworks act as catalysts or barriers to sustainable economic development. Advocates such as Li and Qamruzzaman [60] and Satrovic et al. [61] champion the idea that stringent environmental regulations drive innovation, fostering the advent of green technologies that not only promote economic growth but also ensure resource conservation. This viewpoint is reinforced by the work of Raihan and Tuspekova [62] and Zhen et al. [63], which delineates the pivotal role of environmental regulations in the progression of renewable energy technologies, which thereby contribute to a broader agenda of sustainable development. Additionally, the research conducted by Yuan et al. [64], Hou et al. [65], and Khan et al. [66] underscores the positive externalities of environmental policies, highlighting outcomes like improved public health and reduced healthcare spending as indirect yet significant contributors to economic sustainability. Conversely, a contingent of scholars raises concerns about the potential economic encumbrances introduced by environmental policies. Rempel and Gupta [67] and Lee et al. [68] articulate apprehensions regarding the compliance costs and regulatory burdens that could deter investment, particularly within sectors that are heavily reliant on fossil fuels. Echoing this sentiment, Qadeer et al. [69] and Mohamed et al. [70] caution against the short-term economic repercussions, such as job losses in traditional energy sectors, which might outweigh the anticipated long-term benefits. However, this discourse is further refined by discussions emphasizing the critical importance of policy design in determining the economic impact of environmental regulations. D'Amato et al. [71], Saqib and Usman [72], and Dahmani [73] argue for the strategic crafting of environmental policies, suggesting that the inclusion of carbon pricing and subsidies for green technology can mitigate adverse economic effects and promote sustainability. This premise finds empirical support in the studies of Ahmad and Raza [74], Chunling et al. [75], and Ning et al. [76], which illustrate how policies that encourage public–private partnerships in green technology development can simultaneously spur economic growth and advance environmental sustainability. Empirical analyses conducted by Galeotti et al. [77] and Ngo [78] provide evidence that nations with stringent environmental policies have realized higher rates of economic growth, attributing this success to enhanced efficiency and innovation. This observation is corroborated by Doğan et al. [79], Chishti et al. [80], and Hussain et al. [81], who note the significant reduction in carbon emissions achieved by several developed countries without compromising their economic performance, thanks to effective environmental policies. The sector-specific implications of environmental policies introduce an additional layer of complexity to this analysis. Studies by Genovese and Zoure [82] and Farooq et al. [83] reveal a dichotomy wherein certain sectors may experience short-term challenges due to stringent regulations, while others, particularly those within the green technology domain, thrive, indicating a paradigm shift towards more sustainable economic practices. In summary, the scholarly discourse presents a comprehensive and nuanced understanding of the dynamic relationship between environmental policy and economic sustainability. The consensus leans towards the conclusion that well-designed regulations are instrumental in fostering sustainable economic growth. Despite potential short-term economic challenges, the preponderance of evidence supports the long-term benefits of environmental policies, catalyzing innovation, improving efficiency, and facilitating the transition to a more sustainable economic model, underscoring the necessity for a balanced and critical analysis of these complex interactions.

The complex interplay between fossil fuel consumption, foreign direct investment, trade openness, financial development, and their collective impact on economic sustainability constitutes a rich area of scholarly inquiry. At the heart of this discussion lies the contentious role of fossil fuels, historically pivotal to economic advancement yet increasingly critiqued for their environmental ramifications and sustainability implications. The research by Kirikkaleli et al. [84], Boulanouar and Essid [85], and Yang et al. [86] underscores the negative externalities associated with fossil fuel dependency, such as environmental degradation and public health concerns, which pose challenges to the sustainability of long-term economic growth. In contrast, studies by Muttitt and Kartha [87], Wang and Zhang [88], and Ahakwa et al. [89] highlight the indispensable role of fossil fuels in ensuring short-term economic stability in emerging economies, thus spotlighting the intricate balance between immediate economic benefits and the pursuit of future sustainability. In the realm of foreign direct investment, evidence presented by Amendolagine et al. [90], Luo et al. [91], and Tariq et al. [92] illustrates its potential to spur economic growth, technological innovation, and infrastructural advancements, thereby contributing to sustainability. This narrative, however, is complicated by findings from Guteta and Worku [93] and Liu and Zhong [94], who caution against the environmental and social hazards posed by unchecked foreign direct investment, particularly in jurisdictions with weak regulatory oversight. Similarly, trade openness is celebrated for its ability to invigorate economic activity and promote the diffusion of sustainable technologies and practices, as shown by Khan et al. [95] and Huang et al. [96]. Yet, this optimistic view is tempered by cautionary tales from Woods [97], Aisbett and Silberberger [98], and Guasti and Koenig-Archibugi [99], who warn that enhanced trade could lead to a "race to the bottom" in environmental standards in the absence of stringent regulation. The significance of financial development in directing funds toward sustainable ventures is highlighted by Ikram et al. [100], Yin [101], and He et al. [102], who argue for its crucial role in enabling green investments and initiatives. However, this positive assessment is balanced by insights from Chien et al. [102], Zhang et al. [103], and Irfan et al. [104], which emphasize the need for green finance policies to prevent financial growth from inadvertently supporting environmentally harmful industries. A synthesis of these varied perspectives reveals the deeply interconnected and multidimensional relationships among these factors and their influence on economic sustainability. The literature collectively calls for an informed and strategic approach to policy-making that aligns short-term economic aims with long-term sustainability objectives. Such a strategy requires the integration of energy consumption, foreign direct investment, trade, and financial sector development within a comprehensive framework of sustainable development goals, ensuring that economic progress does not come at the expense of environmental and social welfare.

3. Variable and Model

3.1. Variable

Dependent variable: Pollution-adjusted GDP growth has emerged as an essential metric for assessing economic sustainability, particularly within the context of China's unique environmental and economic landscape. This refined approach to calculating GDP growth integrates the environmental costs associated with pollution and resource depletion, thereby offering a more holistic appraisal of economic vitality. In the face of China's swift industrial expansion, which has precipitated notable environmental degradation, conventional GDP metrics inadequately reflect the true nature of economic advancement. Empirical investigations, such as those conducted by Zhou et al. [103], Umar et al. [104], and Zia et al. [105], on the environmental repercussions of China's economic growth, alongside the analyses of Wei et al. [106], Bai et al. [107], Lin and Zhou [108] on the significance of green GDP for sustainable development and the comparative global studies by Ai et al. [109], Hua and Wang [110], Deng et al. [111], and Xiaofang et al. [112] on pollution-adjusted GDP practices, robustly validate this methodology. These scholarly works collectively affirm that pollution-adjusted GDP growth transcends mere economic indicators by incorporating the sustainability of economic endeavors and taking into account the costs of environmental impairment. Consequently, it stands as an indispensable proxy for evaluating the sustainability of China's economic path, ensuring that economic assessments are in harmony with environmental stewardship, and informing policy directions toward sustainability.

Core variable: Within China's intricate environmental and economic fabric, the consumption of renewable energy and the rigor of environmental policy emerge as cornerstone elements underpinning economic sustainability. The deliberate pivot towards renewable energy, as elucidated by seminal works such as those by Sarkodie et al. [113], Wang et al. [114], Ibrahim et al. [115], and Chen et al. [116], highlights the critical role of renewable resources in diminishing carbon emissions and bolstering energy security. This strategic shift, essential for mitigating China's environmental imperatives, also resonates with broader global sustainability objectives. Concurrently, the exploration of the environmental policy stringency index by scholars like Yuan and Zhang [117], Liu et al. [118], and Zhao et al. [119] underscores a tangible linkage between the intensity of environmental governance and the fortification of economic sustainability. Their collective analysis reveals that stringent environmental mandates have catalyzed innovation within the green technology sector and heightened industrial efficiency, steering China's economy towards a more sustainable trajectory. Moreover, empirical contributions from Ding and Liu [120] and Gatto et al. [121] substantiate the synergistic impact of renewable energy integration and rigorous environmental policies on enhancing economic resilience and sustainability. This body of evidence affirms that China's dedication to renewable energy utilization and the implementation of robust environmental policies are fundamental to cultivating an economic environment that harmonizes environmental stewardship with economic feasibility, thereby establishing a symbiotic relationship between environmental sustainability and economic growth. Hence, this paper employs renewable energy consumption (as a percentage of total final energy consumption) and the environmental policy stringiness index as pivotal variables to encapsulate these dynamics.

Control variable: In the discourse on the nexus between renewable energy consumption, environmental policy, and economic sustainability, particularly within the ambit of China's evolving economic and environmental paradigm, it becomes imperative to contextualize this relationship through the lens of critical control variables such as fossil fuel energy consumption, foreign direct investment, trade openness, and financial development. These elements are foundational to a nuanced understanding of the intricate dynamics that govern the interplay between renewable energy initiatives and economic sustainability outcomes. The cornerstone of China's meteoric economic ascent has been its substantial reliance on fossil fuels. Studies by Rauf et al. [122], Wang and Yan [123], and Pata et al. [124] critically assess this dependency, elucidating the profound environmental repercussions and sustainability challenges it engenders. This body of literature cogently argues for an expedited shift towards renewable energy as a sine qua non for safeguarding long-term economic and ecological well-being. Simultaneously, foreign direct investment emerges as a catalyst in China's economic framework, significantly influencing the transfer of environmentally sustainable technologies and standards. Research conducted by Song and Han [125] and Qin et al. [126] delves into the symbiotic relationship between foreign direct investment and renewable energy endeavors, illustrating how foreign investment is instrumental in propagating green technological innovation and practices, thereby fostering sustainable economic evolution. Moreover, the aspect of trade openness within China's economic stratagem is intricately tied to both environmental and economic metrics. Investigations by Kongkuah et al. [127] and Wang and Lee [128] explore this linkage, positing that, although trade expansion catalyzes economic growth, it concurrently mandates the adoption of robust environmental policies and renewable energy solutions to counterbalance the attendant ecological impacts. Financial development, in its capacity to enable investments in renewable energy and environmental safeguards, plays a pivotal role. Insights from Yang et al. [129], Yin and Xu [130], and Du et al. [131] highlight how a mature financial sector is crucial for channeling resources into green investments, underscoring the importance of financial systems in advancing sustainable economic pursuits. Collectively, these scholarly contributions underscore the importance of incorporating a comprehensive array of economic and policy-oriented variables in the analysis of renewable energy consumption and environmental policy impacts on economic sustainability. By meticulously considering the specificities of fossil fuel dependency, foreign direct investment, trade openness, and financial development, a more precise and holistic evaluation of renewable energy and environmental policy efficacy in promoting sustainable economic growth in China is achievable. This integrative approach not only mirrors the complexity inherent in China's economic fabric but also accentuates the symbiotic relationships between economic policy, environmental integrity, and sustainable development.

To facilitate a comprehensive understanding of the variables employed within this study, Table 1 succinctly encapsulates the essential details pertaining to each variable. This tabulation is designed to enhance the readability and accessibility of this research, ensuring that readers can easily grasp the foundational elements underpinning the analysis.

Table 1. Results of variable description.

Variable	Abbreviation	Definition	Source
Economic sustainability	sus	Pollution-adjusted GDP growth	OECD
Renewable energy consumption	rec	Renewable energy consumption (% of total final energy consumption)	World Bank
Environmental policy	enp	Environmental policy stringency index	OECD
Fossil fuel energy consumption	ffe	Fossil fuel energy consumption (% of total energy)	World Bank
Foreign direct investment	fdi	Foreign direct investment, net inflows (% of GDP)	World Bank
Trade openness	tro	Trade openness is the sum of exports and imports of goods and services measured as a share of gross domestic product	World Bank
Financial development	fid	Domestic credit to private sector (% of GDP)	World Bank

3.2. Model

In the dynamic interplay between China's economic expansion and environmental stewardship, the nexus between renewable energy consumption and the rigor of environmental policies emerges as a focal point of scholarly discourse. The pivot towards renewable energy sources is increasingly acknowledged as a pivotal strategy for aligning China's swift economic development with the imperatives of environmental sustainability. The works of He et al. [132], Abbasi et al. [133], and Liu et al. [134] provide comprehensive analyses on the role of renewable energy consumption in curtailing carbon emissions and enhancing energy efficiency across diverse sectors of the Chinese economy. Overall, their research shows that using renewable energy has a strong positive relationship with promoting economic sustainability. This shows how important renewable energy is for creating a low-carbon, sustainable economic paradigm. In parallel, there has been significant fortification of China's environmental policy landscape in an effort to address the complex issues of pollution, resource scarcity, and climate change. Studies by Liu et al. [135], Fang et al. [136], and Yu and Wang [137] delve into the efficacy of China's environmental policy architecture, with a particular focus on the seminal Environmental Protection Law of 2015, in fostering sustainable economic behaviors. Their findings reveal that stringent environmental regulations not only alleviate environmental degradation but also catalyze green technological innovations, thereby fueling sustainable economic growth. This corpus of research collectively affirms the indispensable role of renewable energy consumption, coupled with stringent environmental policies, in driving China's pursuit of sustainable economic growth. The empirical investigations by Zahoor et al. [138] and Liu and Hei [139] lay a solid empirical foundation advocating for escalated investments in renewable energy. Furthermore, insightful analyses by Dong and Ullah [140] and Zou and Wang [141] elucidate the beneficial economic outcomes of rigorous environmental regulations. Together, these scholarly contributions illuminate the synergistic dynamics between renewable energy consumption and environmental policy rigor in propelling China towards a more sustainable economic future. This underscores the imperative for holistic strategies that judiciously balance the dual objectives of economic growth and environmental preservation. In light of these findings, the benchmark model presented in this paper combines them all into a complete framework for analyzing how renewable energy, environmental policies, and economic sustainability are connected to China's current development path.

$$sus_t = a_0 + a_1 rec_t + a_2 enp_t + a_3 ffe_t + a_4 fdi_t + a_5 tro_t + a_6 fid_t + \epsilon_t. \quad (1)$$

In Equation (1), a_0 represents the constant term, serving as the intercept in the regression equation. The array $[a_1, a_6]$ denotes the range of coefficients that are to be empirically determined through the estimation process. These coefficients quantify the impact of each independent variable on the dependent variable within the model. Additionally, ϵ signifies the white noise component, encapsulating the stochastic elements of the model that account for random variation not explained by the independent variables. In this research, the choice of estimation methodologies is critically examined in light of the dynamic nature of the variables under study, which exhibit a non-stationary mean and variance over time. According to Perron and Ng [142], traditional econometric approaches are inappropriate for these circumstances because they frequently produce false results in the presence of structural shifts. To deal with this problem, the Fourier-Augmented Dickey–Fuller and the Augmented Dickey–Fuller tests are used in this study. These tests include structural breaks to check if the variables in question are stationary. These tests are pivotal in determining the variables' integration order, with both employing a common null hypothesis framework to examine their stationarity characteristics.

$$Y_t = \mu + \rho Y_{t-1} + \epsilon_t \quad (2)$$

In Equation (2), ϵ represents the error component, capturing the residual fluctuations that are unexplained by the model. μ is indicative of the coefficient of determination, reflecting the proportion of variance in the dependent variable that is predictable from the independent variables. Y symbolizes the variables under investigation within the model. Our adaptation involves changing $\Delta Y_t = \mu + \epsilon_t$ by using unit differencing, where $\Delta = 1 - \rho$ shows the slope coefficients for variables that are behind time and changes to 0 when there is a unit root. This adjustment addresses the unit root challenge, integral to the analysis of stationarity and non-stationarity within the dataset. In particular, Equations (3) and (4) show how to handle the unit root issue in the F-ADF test and the ADF test with structural breaks.

$$Y_t = \mu + \beta t + \xi_1 \sin\left(\frac{2\pi kt}{N}\right) + \xi_2 \cos\left(\frac{2\pi kt}{N}\right) + \epsilon_t. \quad (3)$$

$$Y_t = \mu + \beta t + \theta D_t + \vartheta D(T_B)_t + \epsilon_t. \quad (4)$$

In the context of Equations (3) and (4), k signifies the Fourier frequency, while ξ represents the coefficient associated with the slope within the Fourier function. t and N are designated to express the trend component and the number of observations, respectively. β refers to the slope parameter, whereas θ delineates the slope coefficient corresponding to a singular break dummy variable. The dummy variable $D(T_B)_t$ is assigned a value of 1 at the time t equals the breakpoint T_B, and $D(T_B)_t$ is assigned a value of 0 in all other instances. π is defined as 3.14. Furthermore, ϑ encapsulates the slope variable for the regression dummy, with D_t being set to 1 for time periods post-breakpoint ($t > T_B$) and 0 otherwise, where T_B is identified as the breakpoint. Emirmahmutoglu et al. [143], Ilkay et al. [144], Genç et al. [145], and Ursavaş and Yilanci [146] elucidate the formulation of the Fourier-Augmented Dickey–Fuller and the Augmented Dickey–Fuller tests with structural breaks, presented in Equations (5) and (6), respectively. These estimations are refined through the application of an error-correction mechanism and the inclusion of an augmentation factor to address the intricacies of the unit root testing procedure.

$$\Delta Y_t = \mu + \beta t + \xi_1 \sin\left(\frac{2\pi kt}{N}\right) + \xi_2 \cos\left(\frac{2\pi kt}{N}\right) + (\rho - 1)Y_{t-1} + \sum_{i=1}^{p} b_i \Delta Y_{t-1} + \epsilon_t. \quad (5)$$

$$\Delta Y_t = \mu + \beta t + \theta D_t + \vartheta D(T_B)_t + (\rho - 1)Y_{t-1} + \sum_{i=1}^{p} b_i \Delta Y_{t-1} + \epsilon_t. \quad (6)$$

In Equations (5) and (6), ρ is defined as the lag length chosen for augmentation, determined by the lowest values of information criteria, while b represents the coefficient pertaining to the augmented variables. Bahmani-Oskooee et al. [147], Cai and Omay [148], Gil-Alana and Yaya [149], and Doğanlar et al. [150] provide an in-depth exploration of the selection process for the optimal k, discussing its implications for Fourier regularity, the determination of the regression breakpoint T_B, and the calculation of the break fraction λ. Additionally, they propose a methodological approach for assessing model robustness through a physical testing procedure, contrasting constrained and unconstrained model variants to ascertain the statistical significance and model efficacy.

This analysis adopts a methodology premised on the utility of low-frequency components within a Fourier approximation for the identification of latent non-linear dynamics and structural variances within time-series datasets. Structural breaks and alterations tend to manifest as shifts in spectral density functions towards lower frequencies. In this vein, this study leverages the Fourier-Augmented Distributed Lag co-integration test, an approach introduced by Syed et al. [151] and Zaghdoudi et al. [152], to ascertain co-integration relationships among the time-series variables under consideration. The innovative Fourier-ADL method, which integrates considerations of time, structural integrity, and unanticipated structural breaks, serves as the analytical tool for detecting the presence of co-integration. This technique is particularly noted for its superiority over vector error correction model analyses, offering more insightful conclusions. It necessitates evaluating the cumulative effects of both positive and negative economic shocks to determine potential long-term co-integration scenarios. Furthermore, while Fourier functions are adept at identifying structural shifts, the Fourier-based autoregressive distributed lag model obviates the need for a distinct test for structural changes. Li et al. [153], Voumik et al. [154], and Pata and Samour [155] contend that the Fourier-ARDL framework yields more accurate estimates of long-term co-integration than traditional ARDL methodologies, effectively identifying structural changes within the model as delineated in Equation (7).

$$d(t) = \sum_{k=1}^{n} ak \cdot \sin\left(\frac{2\pi kt}{N}\right) + \sum_{k=1}^{n} ck \cdot \cos\left(\frac{2\pi kt}{N}\right). \quad (7)$$

Within the framework of Equation (7), k and n represent the quantity of distinct frequencies under consideration, with π denoted as the mathematical constant approximately equal to 3.14. Additionally, T signifies the total sample size, while t refers to the specific trend component within the dataset. Moving on to Equation (8), the method uses a frequency-selective approach for its analysis, which lets us look at the data in more detail across different spectral components. This technique allows for a more granular analysis, enhancing the precision and depth of this study's findings.

$$d(t) = \xi_1 \sin\left(\frac{2\pi kt}{N}\right) + \xi_2 \cos\left(\frac{2\pi kt}{N}\right). \quad (8)$$

In the context of this investigation, Equation (9) delineates the application of the Fourier autoregressive distributed lag methodology. This approach is instrumental in examining the dynamics at play within the dataset, offering a robust framework for capturing both short-term fluctuations and long-term relationships. The F-ARDL model stands as a pivotal analytical tool in this study, facilitating a comprehensive understanding of the underlying patterns and trends.

$$\begin{gathered}\Delta sus_t = \gamma_0 + \xi_1 \sin\left(\tfrac{2\pi kt}{N}\right) + \xi_2 \cos\left(\tfrac{2\pi kt}{N}\right) + \gamma_1 sus_{t-1} + \gamma_2 rec_{t-1} + \gamma_3 enp_{t-1} + \\ \gamma_4 ffe_{t-1} + \gamma_5 fdi_{t-1} + \gamma_6 tro_{t-1} + \gamma_7 fid_{t-1} + \sum_{i=1}^{p-1} \delta_{1i} \Delta sus_{t-1} + \sum_{i=1}^{p-1} \delta_{2i} \Delta rec_{t-1} + \\ \sum_{i=1}^{p-1} \delta_{3i} \Delta enp_{t-1} + \sum_{i=1}^{p-1} \delta_{4i} \Delta ffe_{t-1} + \sum_{i=1}^{p-1} \delta_{5i} \Delta fdi_{t-1} + \sum_{i=1}^{p-1} \delta_{6i} \Delta tro_{t-1} + \\ \sum_{i=1}^{p-1} \delta_{7i} \Delta fid_{t-1} + \epsilon_t.\end{gathered} \quad (9)$$

In their work, Cil [156], Elbadri et al. [157], and Ozcelik et al. [158] adopted a methodological approach that emphasizes the optimization of the sampling rate, specifically selecting the rate that minimizes the sum of the squared residuals. This approach was further enriched by the incorporation of bootstrap sample simulations to enhance the robustness of the analysis. Furthermore, this study integrates the Fourier-Toda–Yamamoto (hereinafter referred to as the Fourier-TY) causation estimator to scrutinize the causal dynamics present within the time-series data. The causality tests conducted herein leverage the modified Wald technique, a method that transcends the limitations encountered by the Granger causality approach, particularly in dealing with issues of integration and non-stationarity among variables. Unlike the traditional Granger framework, the modified Wald estimator is adept at navigating these complexities. The Fourier TY methodology, renowned for its 'gradual-shift causation statistic', offers a nuanced perspective by accommodating both smooth and incremental structural changes within its causality analysis. This attribute renders the Fourier-TY causation analysis especially adept at providing reliable insights in scenarios characterized by structural discontinuities, thereby offering a significant advancement over conventional Toda–Yamamoto tests. To assess the integration properties of the variables under consideration, the Augmented Dickey–Fuller unit root test was employed. Historically, unit root tests have exhibited a propensity to erroneously uphold the null hypothesis due to the oversight of structural breaks, a limitation highlighted in the work of Perron and Ng [142]. To address this and discern the stochastic properties diverging from traditional dependency and independence frameworks within our data, the BDS test, as introduced by Broock et al. [159], was utilized. This test examines a dataset across a spectrum of embedding dimensions, ranging from two to six, offering a nuanced analysis of the data's stochastic nature. The BDS test stands out among alternative methodologies for its ability to enhance analytical rigor, as noted by Turguttopbaş and Omay [160] and Hasanov et al. [161]. Its principal advantages include the mitigation of model misspecification errors and the reduction of biases stemming from subjective judgment. This approach significantly enriches econometric analysis by providing a more robust framework for understanding the complex dynamics within the dataset. The econometric formulation for implementing the BDS test is detailed in the subsequent equation, setting the groundwork for a comprehensive evaluation of the variables' integration order.

$$BDS_{mt}(\epsilon) = \sqrt{T} + \frac{C_{mT}(\epsilon) + C_{mT}(\epsilon)^m}{\zeta_{mT}(\epsilon)}. \quad (10)$$

Within the framework outlined by Equation (10), T serves to represent the overall sample size, while ϵ is designated as the proximity coefficient, selected through a randomized process. Additionally, $C_{mT}(\epsilon)$ is defined as the standard deviation pertaining to the numerator of the statistic, a value that fluctuates in accordance with the dimension m, as elucidated in the study by Luo et al. [162]. This specification is critical for understanding the mathematical underpinnings and operational mechanics of the model, providing a clear delineation of the variables and parameters that are integral to the econometric analysis.

4. Results and Discussion

4.1. Basic Statistical Analysis

This subsection delineates the core statistical analyses that are conducted in this paper, incorporating an initial descriptive analysis of the variables, which includes the calculation of mean, maximum, minimum, and standard deviation values. Furthermore, this analysis employs advanced econometric techniques, such as the Brock, Dechert, and Scheinkman (BDS) test for examining non-linear dependencies, the Fourier Augmented Dickey–Fuller (Fourier ADF) and conventional Augmented Dickey–Fuller (ADF) tests for evaluating the stationarity of the dataset, and the Fourier-Augmented Distributed Lag (Fourier-ADL) approach for probing into the cointegration relationships among the variables. These methodologies facilitate a thorough exploration of the dataset, shedding light on the stochastic dynamics and the integration levels of the variables in question. Specifically, the BDS test is instrumental in detecting complex dependencies, whereas the Fourier ADF and ADF tests are pivotal in determining the presence of unit roots. The Fourier-ADL test, on the other hand, is critical for identifying and analyzing long-standing relationships within the data. The results derived from this extensive statistical scrutiny are systematically compiled in Table 2, laying a solid empirical groundwork for further econometric analysis.

This study leverages the Fourier autoregressive distributed lag (Fourier ARDL) and Fourier Toda–Yamamoto (Fourier TY) causality frameworks to delve into the intricacies of renewable energy consumption, environmental policy, fossil fuel energy consumption, foreign direct investment, trade openness, financial development, and economic sustainability in China from 1991 to 2022. With our initial findings presented in Panel A of Table 2, the research provides a detailed statistical overview of the variables under consideration. It further examines the complex interplay between renewable energy consumption, environmental policy, fossil fuel energy consumption, foreign direct investment, trade openness, and financial development, as well as their overarching influence on economic sustainability. The descriptive statistical analysis reveals mean values for sus, rec, enp, ffe, fdi, tro, and fid at 0.082, 0.203, 1.256, 0.814, 0.032, 0.419, and 1.239, respectively. This study also articulates the variables' fluctuation ranges, with maximums at 0.131, 0.331, 3.139, 0.889, 0.059, 0.645, and 1.853, and minimums at 0.071, 0.113, 0.000, 0.748, 0.010, 0.241, and 0.842, respectively. This statistical groundwork provides a rich context for a more profound econometric investigation into the determinants of economic sustainability within China's evolving energy consumption and policy framework.

Table 2. Basic statistical analysis.

Panel A: Descriptive Statistics				
Variable	**Mean**	**Maximum**	**Minimum**	**Standard Deviation**
sus	0.082	0.131	0.071	0.017
rec	0.203	0.331	0.113	0.083
enp	1.256	3.139	0.000	1.191
ffe	0.814	0.889	0.748	0.048
fdi	0.032	0.059	0.010	0.013
tro	0.419	0.645	0.241	0.108
fid	1.239	1.853	0.842	0.293
Panel B: BDS Test				
Variable	**2**	**3**	**4**	**5**
sus	0.057 ***	0.085 ***	0.086 ***	0.125 ***
rec	0.179 ***	0.304 ***	0.409 ***	0.475 ***
enp	0.175 ***	0.289 ***	0.353 ***	0.391 ***
ffe	0.175 ***	0.263 ***	0.322 ***	0.352 ***
fdi	0.083 ***	0.148 ***	0.223 ***	0.243 ***
tro	0.143 ***	0.237 ***	0.279 ***	0.286 ***
fid	0.142 ***	0.219 ***	0.241 ***	0.254 ***

Panel C: F-ADF and ADF Unit Root Test			
Variable	**Fourier-ADF Test**	**ADF Test**	**Break Year**
sus	−2.697	−3.735	1994
rec	−8.045 ***	−6.786 ***	2011
enp	−1.903	−3.573	2009
ffe	−1.252	−2.689	2014
fdi	−2.112	−4.177	2011
tro	−1.643	−2.382	2010
fid	−1.326	−1.727	2008
Δsus	−9.938 ***	−5.360 ***	2000
Δrec	−11.015 ***	−6.854 ***	2002
Δenp	−9.297 ***	−8.354 ***	2012
Δffe	−7.059 ***	−5.950 ***	1995
Δfdi	−8.377 ***	−6.284 ***	1995
Δtro	−6.662 ***	−5.731 ***	2009
Δfid	−7.987 ***	−5.476 ***	2009

Panel D: Diagnostic Tests		
Breusch–Pagan–Godfrey Test	**Breusch–Godfrey Serial Correlation LM Test**	**Fourier-ADL Cointegration Test**
1.276	2.689 *	−7.843 ***
CUSUM test	CUSUM of squares	Stable; Stable

Note: * 10% significance level; *** 1% significance level.

Furthermore, the outcomes of the BDS test for non-linearity, detailed in Panel B of Table 2, validate the presence of non-linear configurations within the time-series data utilized in this analysis, as evidenced by statistically significant predicted test statistics. Subsequently, this study employs the Fourier-Augmented Dickey–Fuller (F-ADF) and the Augmented Dickey–Fuller (ADF) with structural break tests to ascertain the integration order of the variables under scrutiny. Results from these rigorous unit root tests are meticulously compiled in Panel C of Table 2. Prior to executing the Fourier ADF unit root examination, an evaluation of the Fourier function's attributes was conducted through F-tests, aimed at determining the statistical significance of the predicted test statistics. This methodological approach ensures a comprehensive assessment of the data's stationary properties and the underlying structural dynamics, laying a robust foundation for subsequent analytical procedures. The findings delineated in Panel C of Table 2, under a 1% significance threshold, indicate that the variables sustainability (sus), environmental policy (enp), fossil fuel energy (ffe), foreign direct investment (fdi), and financial development (fid) exhibit integration at the first difference, denoted as $I(1)$. Conversely, renewable energy consumption (rec) demonstrates integration at level, marked as $I(0)$, accompanied by multiple identified breakpoints, as specified within the parentheses. This mixed integration order of the time-series data justifies the application of Fourier autoregressive distributed lag (F-ARDL) techniques in this analysis. Additionally, diagnostic evaluations, including the Breusch–Pagan–Godfrey and Breusch–Godfrey tests for serial correlation, were conducted, with their results collated in Panel D of Table 2. The outcomes from the cumulative sum (CUSUM) of squares and CUSUM tests further corroborate the stability of the error-correction model's coefficients, as the statistical values are observed to reside within critical bounds. Such stability underscores the model's reliability in formulating recommendations for enhancing economic sustainability through interventions in renewable energy consumption, environmental policy, fossil fuel energy consumption, foreign direct investment, trade openness, and financial development.

Subsequently, this research applies the Fourier autoregressive distributed lag (Fourier-ADL) co-integration test to scrutinize the co-integration characteristics of the time-series variables under investigation. This analytical tool is adept at handling variables irrespective of their integration order, being I(0) or I(1), and is capable of delineating the linear dynamics within the unconstrained error correction framework. The outcomes of the Fourier-ADL examination are presented in Panel D of Table 2, substantiating the existence of enduring linkages among sustainability (sus), renewable energy consumption (rec), environmental policy (enp), fossil fuel energy (ffe), foreign direct investment (fdi), and financial development (fid). These findings confirm the presence of at least one significant long-term co-integrating relationship among the variables, as discerned through Fourier methodologies. Following this, the Fourier-ARDL estimator is employed to meticulously assess the influence of rec, enp, ffe, fdi, and fid on sus, specifically within the Chinese context, offering insights into the dynamics shaping economic sustainability.

4.2. Fourier Long-Run and Short-Run Results and Discussions

This subsection is dedicated to an in-depth examination of the long-term and immediate impacts that renewable energy consumption and environmental policy exert on the sustainability of China's economy, utilizing the Fourier autoregressive distributed lag model. Given China's status as a global economic powerhouse and its significant environmental footprint, understanding the dynamics between renewable energy implementation, policy interventions, and economic sustainability in the Chinese context is crucial. This analysis aims to unravel the nuanced interplay between these variables, providing empirical evidence regarding their collective influence on China's path towards a greener and more sustainable economic framework. The empirical findings from this rigorous investigation are systematically compiled in Table 3, offering a comprehensive overview of the potential long-run and short-run effects that renewable energy consumption and environmental policy adjustments have on the economic sustainability of the Chinese economy.

The findings presented in Table 3 corroborate the positive impact of renewable energy consumption on China's economic sustainability, reflecting the country's efforts to harmonize its swift economic expansion with environmental stewardship. The analysis reveals that a 1% increase in renewable energy consumption correlates with a 0.255% long-term and a 0.241% short-term boost in economic sustainability. This evidence aligns with China's strategic pivot towards renewable energy investments to mitigate carbon emissions and foster a sustainable development model. Contrasting and complementary insights emerge from the scholarly discourse on this topic. For instance, research by Solarin et al. [163] and Hao et al. [164] echoes the positive linkage between renewable energy use and sustainable economic growth in China, albeit with slightly more conservative impact assessments, potentially due to variances in analytical methodologies or study periods. In a nuanced argument, studies by Jiang et al. [165] and Fatima et al. [166] suggest that the efficacy of renewable energy in promoting economic sustainability substantially hinges on the adoption level of technology and energy utilization efficiency. They propose that technological advancements and infrastructural development could significantly enhance the sustainability benefits of renewable energy. Additionally, inquiries by Fan and Hao [167], Chen et al. [168], and Lin and Xu [169] into regional differences reveal that the economic sustainability gains from renewable energy policies are more significant in economically advanced regions, indicating an uneven distribution of renewable energy benefits across China. This collective body of work underscores a general consensus regarding the beneficial effects of renewable energy on economic sustainability in China, although it acknowledges variations in the magnitude of these effects. The diversity in outcomes across these studies illuminates the intricate dynamics of China's energy sector and the various determinants of the renewable energy–economic sustainability nexus. It highlights the imperative for policy frameworks that are sensitively attuned to regional disparities, technological progress, and infrastructural needs to fully leverage the potential of renewable energy for sustainable development.

Table 3. Results of Fourier long-run and short-run effects.

Variable and Model	Model (1): Long-Run	Variable and Model	Model (2): Short-Run
rec	0.255 *** (6.324)	Δrec	0.241 *** (4.976)
enp	0.649 *** (5.209)	Δenp	0.571 *** (7.447)
ffe	−0.304 *** (−2.838)	Δffe	−0.105 ** (−2.108)
fdi	0.211 * (1.853)	Δfdi	0.192 ** (2.318)
tro	0.293 * (1.628)	Δtro	0.307 * (1.748)
fid	0.269 *** (3.916)	Δfid	0.289 *** (4.621)
		ect_{-1}	−0.136 *** (−8.455)

Note: * 10% significance level; ** 5% significance level; *** 1% significance level; *t*-statistical value shown in parentheses.

The findings delineated in Table 3 elucidate the constructive role of environmental policy rigor, as measured by the environmental policy stringency index, in bolstering China's economic sustainability. Notably, the analysis demonstrates that a marginal increase (1%) in environmental policy stringency correlates with a substantive rise in economic sustainability—0.649% in the long-term and 0.571% in the short-term. This revelation is particularly salient against the backdrop of China's concerted efforts to weave environmental prudence into its economic expansion strategy, thereby seeking an equilibrium between growth and ecological stewardship. The results of this study, while aligning with previous research, also present distinct perspectives. Studies by Yuan and Zhang [117], Gu et al. [170], Wang et al. [171], and Xie et al. [172] have similarly underscored the pivotal influence of stringent environmental policies on sustainable economic development in China, albeit with marginally lower impact estimates. Such discrepancies likely emanate from methodological divergences or differences in the dimensions of environmental policy stringency under scrutiny. Conversely, investigations by Shi et al. [173] and Hsu et al. [174] into the variegated impact of environmental regulations on economic performance across China's regions reveal a nuanced landscape. Their findings indicate that, while rigorous environmental policies foster economic sustainability in more developed regions, their efficacy is diminished in less affluent locales, underscoring the intricate relationship between regional economic conditions and policy impact and suggesting a non-uniform benefit distribution of environmental stringency across the nation. Furthermore, analyses by Zhang and Du [175], Zhang et al. [176], Wang et al. [177], and Dong and Ullah [140] introduce a critical perspective, acknowledging the potential short-term economic drawbacks of stringent environmental policies, notwithstanding their undisputed long-term sustainability advantages. This viewpoint accentuates the complexity of navigating the sustainability trajectory, which may necessitate temporary compromises. In juxtaposition with these scholarly contributions, the present analysis affirms the beneficial impact of environmental policy stringency on China's economic sustainability, although it acknowledges variations in the magnitude and nuances of the effect. These disparities accentuate the dynamic essence of China's environmental policy framework, highlighting the imperative for nuanced, regionally tailored policy measures that reconcile the immediacy of economic imperatives with the exigencies of long-term ecological and economic sustainability. Such strategic policy formulation is essential to optimize the sustainability dividends of environmental rigor without curtailing economic vitality.

The findings from Table 3 reveal a complex interplay between various economic drivers and their impact on China's pursuit of economic sustainability. Specifically, foreign direct investment, trade openness, and financial development emerge as key proponents of sustainability, enhancing economic resilience and growth in both the short- and long-term. Conversely, reliance on fossil fuels is identified as a detriment to sustainable economic progress, highlighting the environmental and economic costs associated with non-renewable energy consumption. This nuanced analysis aligns with and diverges from existing research in several critical areas. For instance, Wang and Jiang [178], Fang et al. [179], and Zhao and Li [180] examined the role of foreign direct investment in China's economic sustainability, suggesting that, while foreign direct investment significantly contributes to economic growth, its sustainability impact is contingent upon its alignment with green investment practices. This underscores the dual-edged nature of foreign direct investment, which can either bolster or undermine sustainability based on the environmental standards that are enforced. Similarly, research by Jun et al. [181], Qi et al. [182], and Han et al. [183] on trade openness and sustainability in China indicates that increased trade, while beneficial for economic expansion, necessitates stringent environmental regulations to mitigate the adverse effects on sustainability. This finding resonates with the positive correlation between trade openness and sustainability noted in Table 3, but adds a layer of complexity regarding the environmental implications of expanded trade. In the realm of financial development, studies by Yan and Haroon [184] and Zahan and Chuanmin [185] highlight the pivotal role of financial markets in mobilizing resources for sustainable investments. However, they caution against the potential for financial development to exacerbate environmental degradation in the absence of targeted green financing mechanisms. This perspective enriches our understanding of financial development's positive impact on sustainability by emphasizing the importance of directing financing towards environmentally sustainable projects. Contrastingly, the analyses by Wei et al. [186], Rahman et al. [187], Baz et al. [188], and Zahoor et al. [138] on the impact of fossil fuel consumption mirror the findings in Table 3, presenting a clear negative association with economic sustainability. Their work further delves into the potential for renewable energy sources to counteract the sustainability costs associated with fossil fuels, advocating for an accelerated energy transition in China. Moreover, the adjustment rate of 13.6 percent back to long-run equilibrium following a shock, as identified in the analysis, highlights the resilience of China's sustainable economic system. This finding suggests an inherent capacity within the economy to recover from disturbances, albeit at a moderate pace, underscoring the need for policies that enhance the elasticity of China's economic sustainability framework. Collectively, these discussions illuminate the consensus and divergences within the scholarly discourse on the determinants of economic sustainability in China. While foreign direct investment, trade openness, and financial development are universally recognized as crucial for sustainability, their beneficial impacts are nuanced due to considerations of environmental policy and green investment practices. The unequivocally negative effect of fossil fuel consumption further emphasizes the urgency of transitioning to renewable energy sources. These insights advocate for a holistic policy approach that harmonizes economic growth with environmental conservation to ensure the long-term sustainability of China's economic development model.

4.3. Fourier Toda-Yamamoto Causation Test

The Fourier autoregressive distributed lag model serves to delineate and measure the dynamic interplay between renewable energy consumption, environmental policy implementation, and their cumulative effects on China's economic sustainability across both temporal spectrums. Although this approach sheds light on variable interrelations, it stops short of establishing causality. Enter the Fourier Toda–Yamamoto causation test, which augments the analytical framework by rigorously assessing causative linkages between variables. This test is particularly adept at accounting for non-linear trajectories and structural shifts within time-series data, a crucial feature when analyzing economic indicators that are prone to fluctuations from policy adjustments, market perturbations, or other externalities. Leveraging both the Fourier autoregressive distributed lag model and Fourier Toda–Yamamoto causation test, this investigation sharpens its policy relevance, pinpointing interventions poised to bolster economic sustainability. This dual-methodology approach not only illuminates causal dynamics among key variables but also equips policymakers with the empirical evidence required to craft targeted strategies in the realms of energy, environment, and economic development. The findings of this comprehensive analysis are encapsulated in Table 4.

Table 4. Results of Fourier Toda–Yamamoto causation test.

Null Hypothesis	*t*-Statistic
rec does not Granger cause sus	5.805 ***
enp does not Granger cause sus	3.328 ***
ffe does not Granger cause sus	7.568 ***
fdi does not Granger cause sus	4.127 ***
tro does not Granger cause sus	2.151 **
fid does not Granger cause sus	2.109 **

Note: ** 5% significance level; *** 1% significance level; *t*-statistical value shown in parentheses.

The Fourier-Toda–Yamamoto causality analysis delineated in Table 4 substantiates the critical and singular influence of several macroeconomic determinants—namely, renewable energy consumption, environmental policy rigor, the utilization of fossil fuels, foreign direct investment, trade liberalization, and financial sector evolution—on China's economic sustainability trajectory. This analysis, revealing a lack of reciprocal causality, not only aligns with but also deepens the insights from prior regression analyses, accentuating the pivotal contributions of these variables to the nuanced matrix of influences propelling China towards sustainable economic practices. Research by scholars such as Sadiq et al. [189] and Yi et al. [190] reinforces the vital role of renewable energy in curtailing environmental harm and fostering economic resilience, spotlighting beneficial externalities like job creation and innovation. In parallel, studies by Chen et al. [6] and Jiang et al. [191] underscore the transformative potential of stringent environmental policies in catalyzing industrial innovation and efficiency, thereby charting a path to sustainability. Moreover, analyses by Shahid et al. [192] and Qian and Zhou [193] articulate foreign direct investment's dual role in capital infusion and the propagation of green technologies, marking it as instrumental in achieving environmental sustainability goals. Furthermore, investigations by Qing et al. [194] and Bakhsh et al. [195] elucidate the critical contributions of trade openness and financial sector maturity to China's sustainability efforts, highlighting how these factors enhance resource allocation efficiency and provide essential funding for sustainable initiatives. Together, these scholarly contributions provide comprehensive insights into the causal dynamics identified by the Fourier-Toda–Yamamoto causality analysis, offering a layered understanding of how each factor underpins China's sustainability agenda. They underscore the complexity of China's sustainability endeavors and advocate for an integrated policy framework that synergistically harnesses renewable energy, environmental regulation, foreign direct investment, trade openness, and financial innovation to navigate the country towards a sustainable economic future.

5. Conclusions

In this investigation, leveraging the Fourier autoregressive distributed lag and Fourier Toda–Yamamoto causality techniques, we scrutinized the influence of renewable energy consumption and environmental policy on the economic sustainability of China, in a period spanning from 1991 to 2022. Our analyses reveal that both renewable energy usage and the implementation of robust environmental policies have significantly bolstered China's economic sustainability. Moreover, our study identifies that foreign direct investment, trade openness, and the advancement of financial sectors have further supported China's sustainable economic trajectory. Conversely, reliance on fossil fuels has been found to detract from these sustainability efforts. Our Fourier-Toda–Yamamoto causality findings underscore the indispensable roles that renewable energy consumption and environmental policy play as fundamental drivers of China's economic sustainability. This comprehensive analysis highlights the importance of integrating sustainable energy and environmental considerations into the broader economic development strategy of China, emphasizing the need for a balanced approach that fosters economic growth while ensuring environmental stewardship and sustainability.

The insights from this study illuminate strategic directions for China's sustainable development policies. Firstly, it is paramount for the Chinese government to enhance incentives for renewable energy adoption, including subsidies, tax benefits, and investments in green infrastructure, to diminish fossil fuel dependency and its adverse effects on economic sustainability. Secondly, the pivotal contribution of environmental policies necessitates the reinforcement and rigorous application of environmental regulations, safeguarding economic advancement from ecological compromise. Thirdly, the favorable influence of foreign direct investment, trade liberalization, and financial sector growth on sustainability highlights the necessity of fostering an investment-friendly climate and promoting financial sector innovation to bolster sustainable economic endeavors. Finally, these findings call for a cohesive policy architecture that synergizes efforts in the realms of renewable energy, environmental conservation, and economic growth, crafting a well-rounded and shock-resistant pathway to sustainable development for China.

This investigation into the interplay between renewable energy, environmental policy, and economic sustainability in China illuminates significant relationships but also encounters limitations that herald further scholarly exploration. Firstly, this study's macro-level perspective may obscure the nuanced effects of policies and energy consumption at the provincial or municipal level, suggesting a pivot towards more granular, localized studies. Secondly, by focusing on a predefined set of variables, this analysis may overlook other pivotal factors like technological advancements, societal sustainability perceptions, and the implications of non-renewable energy sources, indicating a need for a broader investigatory scope. Thirdly, while the methodologies applied in this study are comprehensive, the adoption of alternative statistical and econometric techniques could offer additional validation and depth to the findings. Fourthly, this study does not explicitly address the impact of the COVID-19 pandemic for the years from 2019 to 2022 within its analytical framework, an oversight that may overlook the pandemic's unique influence on renewable energy consumption, environmental policy, and economic sustainability in China. Future studies are encouraged to incorporate dummy variables for the years from 2019 to 2022 to specifically investigate the differential impacts of the COVID-19 pandemic on sustainable development metrics and policy effectiveness. Lastly, this study's scope, primarily domestic, omits the broader international context—such as trade dynamics, global environmental protocols, and cross-national comparisons—that could enrich understanding and strategy regarding China's sustainability efforts. Consequently, future research could benefit from extending the study period, delving into micro-level dynamics, broadening the variable spectrum, diversifying methodological approaches, and contextualizing China's sustainability narrative within the global milieu to cultivate a more holistic comprehension of the determinants of economic sustainability.

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