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Abstract

Clean energy has sparked the importance of a sustainable environment and economic production in China. The concerns of climate and global warming can be solved with the adoption of clean energy. This study investigates the potential long-run connection amid economic production, labor, and capital stock with clean energy employing data from the years 1990-2020 in China. The combination of long-run estimates with Granger causalit678y has been employed. The observed output indicates that there is a long-run connection among these variables in an equilibrium sense. Also, changes in clean energy are significant in explaining changes in economic production. The outputs of the causality test corroborate that clean energy is causing economic production. The estimated elasticity of clean energy with respect to production is statistically significant in the long run. The findings imply that the development of new energy technologies for clean energy should be incorporated into the energy mix to balance the supply-demand gap.

Keywords: Energy Sustainability; Economic Production; Clean Energy; Long Run

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Abstract

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Introduction

There are dire concerns about clean energy and economic sustainability and this question gained attention in the state-of-the-art literature. It is well documented that economic sustainability can be measured with the growth of gross domestic output (GDP) which in turn depends on many factors including energy (Abbas, 2013)-4,9-(Menegaki, 2018) Stern, 2004. The seminal work in energy-GNP dynamics by Kraft and Kraft 1978) has led many other researchers to date which examine the relationship using different countries

(Omri, 2014) variables Shakeel, 2021 and econometric methods Smyth, 2015.

It is precisely clear that energy is a significant factor in production, and nothing can be produced and supplied without using energy. Nevertheless, consumption of the energy input is pivotal in the logistics and supply chains of the production therein more economic production. This implies that more economic production necessitates more energy utilization therein increases the economic value of GDP Feenstra, 2015 Lean, 2010. This also comprehends the fact that sustainable economic production requires a sustainable energy supply. There is no way to produce goods without using energy and much of the energy use is based on fossil fuels sources, especially in China World Bank, 2022 This has caused a debate of pollution-related concerns in the world generally and in China specifically. The country is trying to cultivate the system of production by increasing clean fuels in the economy. This will confirm the targets of sustainable development goal (SDGs) 2030 as well.

Clean energy significantly contributes to GDP growth by enhancing energy resource efficiency, creating a cleaner environment, and reducing production costs using renewable and non-renewable national clean resources. These factors lead to economies of scale, better means of exploitation, and increased output demand through forward and backward linkages. Although extensive research exists on the relationship between energy and GDP, there is limited evidence specifically linking clean energy use and economic output, particularly in China. While energy conservation is crucial for sustainability, energy consumption remains essential for achieving a sustainable economy. This highlights the complexities of the sustainability agenda, such as the slow and insufficient adoption of renewable energies due to their high costs and the recent emphasis on circular economy practices and climate change mitigation.

The continued reliance on fossil fuels places nations in a policy dilemma, forcing them to choose between economic production and a clean environment. Although energy is vital for economic growth, it must be consumed responsibly, regardless of the energy source. Clean energy, however, should take precedence over fossil fuels due to pressing concerns like environmental change and heating waves, leading to reduced pollution and sustainable production. The discussion underscores the critical role of energy in GDP, but there is a notable lack of evidence-based research on the impact of clean energy on economic output, especially in China. Moreover, the role of these variables has been relatively underexplored, particularly through the production function approach.

The existing studies focused on other regions concluded that the use of a production framework is critical in determining the importance of energy in production growth Lean (Shakeel, 2014).

The findings also suggest that energy conservation strategies are somewhat needed for enhancing the GDP. The researchers mostly employed the modeling framework using aggregate energy. This was discussed earlier fossil fuel-based sources have a huge share in the energy mix, especially in China. Therefore, focusing on clean fuel sources will be of much insight for making optimal decisions in the economy. Also, if energy conservation affects sustainable production, countries should consider delaying energy conservation till the penetration of clean energy and its feasibility (Menegaki, 2021; Alper, 2016; Koçak, 2017).

Jiang et al. 2022 document that China is among the major nations that consume a huge amount of energy including fossil fuels and the country has set a double carbon target to control pollution. The local market structure of China demonstrates resiliency although there was a reduction in domestic subsidy in 2020, a post-crisis period. China has increased its share of clean energy including solar panels by 15.7% as compared to 2019. Thus, the economy of China has been developing in the last 30 to 40 years. Additionally, the structure of the economy plays a significant role in influencing energy demand and the adoption of clean energy technologies. For example, China's rapidly expanding service sector is generally less energy-intensive than its manufacturing sector. This economic shift could contribute to reduced energy consumption and encourage the transition to cleaner energy sources. The present study attempts to provide robust findings for the long-run dynamics among GDP, labor, capital, and clean energy in China. This will lead to developing potential outcomes to answer the contemporary energy policy questions vis-a-vis sustainable economic GDP and inter-generational concerns for a clean environment. The work opts for an aggregate production-based model to gauge the significance of clean energy by estimating the short and long-run coefficients and therein role of these fuels and delinquent impacts on economic production in China. The existing examination tries to content the significance of clean energy-GDP dynamics in a much-refined manner. This study uses both renewable and non-renewable energy combined to measure clean energy as the share of renewable energy is relatively very small in the energy mix of the country. There is no evidence on this topic in this manner and thus our study contributes significantly to cover the gap in China. This will also have bearings for the energy conservation policy and the track of sustainable environment and production.

The course of the remaining material will be preceded by a review of related contemporary studies in the second section. Hypothetical structure and data delineation have been discussed in the third section. The econometric approach has been outlined in the fourth section. Outcomes are discussed in the fifth section and the last section elaborates on the concluding remarks of this study.

Review of Literature

The present segment opts to evaluate and review major literature on the topic of energy and economic sustainability. The nature of the studies is very germane to the model development of this study. Notwithstanding, the present discussion will attempt to develop an understanding of the linkages of the variables a.k.a clean energy and economic GDP, yet this will also discuss the gap of empirical evidence on the issue.

The research conducted by Narayan and Smyth 2009 delves into the long-run linkages between electricity and economic output in six Middle Eastern economies during the annual period 1974-2002. The study employs panel causality tests and establishes a unidirectional causal link from electricity to economic output. However, it focuses solely on electricity, leaving a gap for exploration of linkages with other clean fuels.

Similarly, Lean and Smyth 2010 examine the economic connections in Malaysia for the annual period, noting long-run linkages between electricity, exports, and GDP. While indicating one-way causality from electricity to exports and from exports to GDP, the study concentrates exclusively on electricity, creating a gap in the analysis of other clean fuels.

Sadorsky 2011, in a study covering eight Middle Eastern economies during the annual period 1980-2007, identifies long-run linkages using a multi-variable framework. Panel causality tests reveal one-way causality from exports to energy and two-way causality between imports and energy. The study focuses on aggregated energy, leaving room for the exploration of linkages with clean fuels.

In a South American context, Sadorsky 2012 identifies long-run and causality relationships between energy consumption, GDP growth, and exports or imports in seven economies from 1980 to 2009. The study employs panel co-integration and causality tests, revealing a feedback link between energy and trade. However, the study overlooks the role of clean fuels in this dynamic connection.

Farhani et al. 2014 investigate the links between gas usage and output production in France, using an annual dataset. Employing a production framework with auto-regressive distributed lags (ARDL) methods, the study finds evidence of a long-term connection but does not address other fuels, including clean sources.

Raza et al. 2015 examine the long-run association between energy and economic production in Pakistan using ARDL and Johansen approaches of co-integration. While causality tests confirm the role of trade in energy consumption, the study uses aggregate energy data, neglecting the specific contribution of clean fuels to the country's GDP.

Menegaki and Tugcu 2018 note a two-way causality between energy use (proxied with renewable and non-renewable sources) and GDP in Asia from 1990 to 2015. They argue that energy conservation may harm sustainable economic GDP. However, the study lacks country-specific results and does not explore the impact of clean energy on GDP.

Shakeel and Ahmed 2020 find a long-run panel co-integration among GDP, energy, and trade in the production function of South Asian economies. Their study, based on annual data from five countries, identifies a two-way causal association between energy and trade. Yet, it leaves a gap in understanding the dynamics of clean energy in China and other regions.

Bhuiyan et al. 2022 assert that adopting renewable energy improves the output of both developed and developing nations. While they provide important results based on a systematic review of peer-reviewed journal articles, the study does not address the role of other clean fuels.

Awan et al, 2022. Stern, 2000 examines the association between renewable energy, urbanization, and FDI in ten emerging economies from 1996 to 2015. Using methods of moments quintile regression, they find that renewable energy reduces pollution across quintiles. However, the study does not explore the role of clean fuels and their impact on output in other regions.

Abbasi et al. 2022 explore environmental factors, including fossil fuel, renewable energy, and GDP, using dynamic ARDL simulation and frequency domain causality. They highlight the increase in CO_2 emissions from fossil fuel sources and the vice versa relationship with renewable energy. Despite their significant contribution, the study lacks an examination of the dynamic association between clean fuels and GDP in China.

In another study, Abbasi et al. 2020 investigate the asymmetric links between renewable and non-renewable energy and terrorism in Pakistan. Utilizing nonlinear ARDL methods, they identify positive and negative changes affecting the link between renewable energy and terrorism. While providing novel findings, the study falls short in exploring the relationship between other clean energy sources and GDP.

Nadeem et al 2023 employed structural break models to assess the role of clean energy in exports and GDP in China. They applied a production framework to examine the relationship between the variables. They found that there is a long run relationship between these variables while clean energy is three times less in magnitude as compared to fossil fuel in China. They concluded that there should be a policy shift towards clean energy to increase the magnitude of clean fuels in countries like China. Their findings are novel yet confined in the manner of not using other econometric models and variables.

Thus, the extant studies infer conclusions about the sensitivity of economic development to diverse energy policy tools; this assumes that dependency on energy based on fossil fuels should be reduced to improve pollution conditions. This is however clear that these studies leave the gap between clean energy and sustainable economic production. The present work endeavors to cover this gap in China.

Theoretical Model and Data Description

The use of production function is extensively done and there is a plethora of research that provides the importance pertaining to the use of this framework. Therefore the present study utilized the notion that production (Y) in the economic system depends on the availability of labor, (L), and capital, (K).

$$Y = Af(K, L) \quad 1$$

Pokrovski 2003 substantiates that energy has been an exterior factor to substitute for labor in many technological processes. Under mentioned the contemporaneous evidence mentioned in section 2, the present study is taking clean energy, (E) as one of the arguments of equation 1. Then adding the Solow residual (A) and parameters of the inputs, equation 1 will be written in the following manner.

$$Y = A_0 K^{\propto 1} L^{\propto 2} E^{\propto 3} \quad 2$$

The data of all the variables has been obtained from World Bank data source 2022 The description of the variables is that Y denotes real GDP at constant dollars, K is capital formation to GDP ratio at constant dollars, L is aggregated labor force, E is clean fuels measure with adding renewable and nonrenewable clean sources. Clean energy is non-carbohydrate power and alternative and nuclear energy is the name of the variable measured for clean energy at World Bank source.

Applying the linearity of the previous equation 2, we get the proposed equation.

$$y_t = \alpha_0 + \alpha_1 k_t + \alpha_2 l_t + \alpha_3 e_t \quad 3$$

The study used annual time series of data of GDP to measure production, labor force, capital stock, and clean fuels from the period 1990-2020 for China. The data has been obtained from the World Development Indicator.

The technical contribution of the present works rests in the adoption of aggregated production functions using clean energy with other variables. The employment of production function provides complementarities among energy and other inputs (labor and capital). This will also tackle the potential of omitted variable bias which could lead to inefficient estimates of the model (ref. 32).

Econometric Method

The succeeding approach has been used to estimate the evidence of long-term links among the variables.

Test of Unit Root

There are many tests for checking the order of integration to identify the order of integration of the variables. The test corroborates the non-stationarity properties of the covariant both in level and in difference form. For series having deterministic elements in the shape of a constant or a linear trend; Elliott et al. 1996 a.k.a ERS formulated an asymptotically step optimal test to discover a unit root. So, we used this ERS test reported in Table 3.

Co-integration Test

The second place in the journey of examination is the potential link among the time series of the model presented in the previous section. To execute the job of finding potent long-run connection/existence, the formulation long-run test used the vector approach given in the equation.

$$Z_t = C_0 + C_1 Z_{t-1} + C_2 Z_{t-2} + C_3 Z_{t-3} \ldots\ldots\ldots\ldots\ C_p Z_{t-p} + \mu_t \quad 4$$

The study also employs the test of Hansen's (1992) parameter instability as well.

Long Run and Vector Error Correction Model with Causality

The computation of the error correction model has been gauged by utilizing equation 4.1 and its establishment method has been provided by Johansen and Julius 1990

$$\Delta y_t = \propto_1 + \sum_{j=1}^{p} \beta_{11j}\, \Delta y_{t-j} + \sum_{j=1}^{p} \beta_{12j}\, \Delta k_{t-j} + \sum_{j=1}^{p} \beta_{13}\, \Delta l_{t-j} + \sum_{j=1}^{p} \beta_{14}\, \Delta e_{t-j} + \gamma\mu_{t-1} + \omega_t \quad 5$$

The direction of causation is the final step to finding the dynamic links between the variables. Toda and Yamamoto's 1995 test is applied, and it does need a priori verification of the non-stationarity of the variable with the same positive order and existence of co-integration.

$$y_t = \propto_1 + \sum_{j=1}^{p} \beta_{11j} y_{t-j} + \sum_{j=1}^{p} \beta_{12j} k_{t-j} + \sum_{j=1}^{p} \beta_{13} l_{t-j} + \sum_{j=1}^{p} \beta_{14} e_{t-j} + \gamma_{16} \mu_{t-1} + \omega_{1t} \quad 6$$

$$e_t = \propto_2 + \sum_{j=1}^{p} \beta_{21j} y_{t-j} + \sum_{j=1}^{p} \beta_{22j} k_{t-j} + \sum_{j=1}^{p} \beta_{23} l_{t-j} + \sum_{j=1}^{p} \beta_{24} e_{t-j} + \beta_{26} \mu_{t-1} + \omega_{2t} \quad 7$$

Wald test statistics cater to the insignificance of the causality path in both equations and keep restrictions on β_j's = 0, respectively.

Empirical Results and Discussion

There are different results that have been estimated as per section 4.

The summary statistics given in Table 1 reveal mean values of GDP, labor, capital, and clean energy are closely associated. Jarque-Bera test reveals that the sample of these time series is from a normal distribution. Therefore, we can use the standard estimation process to further unearth the dynamic linkages among these variables.

Table 1

Descriptive Statistics

	GDP	Labor	Capital	Clean Energy
Mean	29.1	20.4	0.25	20.97
Median	29.1	20.4	0.20	16.91
Maximum	30.3	20.5	0.44	34.08
Minimum	27.6	20.2	0.084	11.34
Std. Dev.	0.847	0.06	0.133	8.591
Skewness	-0.153	-0.81	0.223	0.25
Kurtosis	1.74	2.35	1.349	1.29
Jarque-Bera	2.21	4.09	3.90	4.24
Probability	0.330	0.12	0.142	0.11
Sum	932.9	653.7	8.24	671.1
Sum Sq. Dev.	22.2	0.146	0.555	2288

We also conducted a correlation analysis presented in Table 2. The GDP has a close correlation with labor, capital, and clean energy as depicted by their coefficients.

Table 2

Spearman Rank Correlation

	Y	L	K	CE
Y	1			
L	0.91	1		
K	0.90	0.71	1	
CE	0.81	0.61	0.66	1

In the next sub-sections, we provided the standard estimation for the potential long-run linkages. The test of unit root provides guidelines for the non-stationarity of the time series. If they are unit roots, then these series can be tested for the potential long-run equilibrium link with a cointegration test. After that, short-run dynamics and error corrections can be estimated with the error correction model. Then in the final step, we can calculate the direction of causality to understand the energy hypothesis and its implications. The outcomes are given and interpreted in the next part.

Unit Root

The empirical outputs of the Dickey fuller GLS unit root test have been discussed in Table 3. This test has been used with intercept only for all variables except for labor wherein intercept and trend have been incorporated. Specifically speaking, the empirical estimates corroborate that economic production (Y), capital(K), labor (L), and clean energy (E) are integrated of order one i.e. I(1) process or non-stationary series. Likely the difference between these series shows that these variables are different stationary processes.

Thus, we anticipate a potential long-run connection as per economic and econometric theory.

Table 3

Dickey-Fuller GLS Unit root test

Variables	Estimate	critical	Estimate	critical
Y	-2.18*	-1.95	-2.18	-1.95
k	-1.14**	-1.95	-2.24	-1.95
l	-1.16**	-3.19	-3.93	-3.19
e	0.24**	-1.95	-5.29	-1.95

*Note: * and ** denotes the significance at 10 % and 5 % respectively.*
Value is estimated with intercept only while labor is estimated with intercept and trend.

Estimates of Long Run Co-integration

The empirical outputs that manifest the potent long-run connection among the time series of the proposed model have been presented in Table 4. The tests developed in the methodology section have been employed to gauge the long-run connections from equation 3.3. The estimates have been computed in the production function with clean energy as energy input. This augmentation of clean energy could be of much insight into developing a better understanding of energy policy and economic sustainability in China.

The presented trace and maximum Eigen statistics informs that there is a long run affiliation amid the variables of the presented Model. It is pertinent to mention that there is an indication of co-integration by trace and Eigen statistics at a 5 percent level of significance. Thus, there is data-based evidence for a potent long-run connection among the select variables of the model. The findings of trace statistics are somewhat less significant for the verification of long-run association. Notwithstanding, Hanson's instability test also confirms the presence of co-integration as alluded to earlier. The results are indicative of the significance of clean energy in economic production in the long run.

Table 4

Results of Co-integration

Trace		P-value	Max-Eigen	P-value
None*	50	0.03	29	0.02
At most 1	20	0.41	13	0.43
At most 2	6.9	0.58	6.7	0.51
At most 3	0.15	0.68	0.15	0.68

Trace		P-value	Max-Eigen	P-value
**Hansen Lc Statistics	0.58	0.15		

** denotes significance value at a 5% level of significance. **Trends included:3*

Further validation of the potent extended links in variables of the model could be observed through the estimation of the error correction model. It is pertinent to state that the value of the error term with a negative sign and having statistical significance is perceived to be the evidence of an equilibrium link among time series and vice versa. The Hansen instability test also accepts the null of co-integration among the variables. Therefore, in the next step, we computed the vector error correction (VECM) of the proposed model.

Estimates of VECMs and Elasticity Coefficients

The verification of co-integration could be done with the help of computing the VECMs of the model as mentioned earlier. The approach of modeling the variables is consistent with that of the previous section employing the production function.

Therefore, the VECMs are based on clean energy has also been estimated as a dependent variable (see Table 5).

The computed outputs of the error correction terms show that economic production with standard inputs and clean energy are significant in restoring long-run convergence levels among the variables. This is depicted by a significant value of the error term with a -0.10 value implying that 10 percent of the error after any shock will be restored in a year and then next year remaining of the error will be restored at this 10 percent rate and so on till convergence is achieved. The residuals from the estimated equation of VECMs also confirm this finding (See Figure 1).

Likewise, VECMs with clean fuels as dependent variables also corroborate the existence of an error correction mechanism, and therein implies that changes in economic production, labor, and capital are also significant in explaining changes in clean energy. Thus, there is evidence of a two-way connection among the variables which will be further verified by the causality analysis in the next sub-section.

Table 5

Results of VECM and Coefficients

OUTPUT (Y)	Long Run	t-value	Short Run	t-value	VIF**
Labor	2.46*	3.33	0.59*	2.09	3.25
Capital	0.09	0.14	1.90	1.28	1.29
Clean Energy	0.38*	4.38	6.7	0.02	4.89
ECT	-0.10*	3.18	F-Value	9.20*	-----
			R^2	0.65	

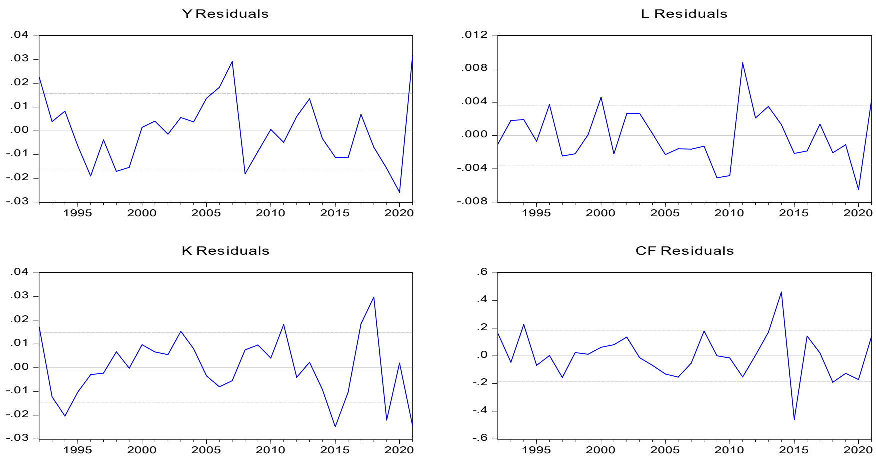
** denotes the significance value at a 5% level of significance.** VIF=10 is significant*

The value of the long-run coefficients for the estimated model demonstrates that labor and clean energy are significantly affecting economic production while capital is found statistically insignificant in this model. Specifically, a one percent increase in labor will increase economic production by 2.46 percent while a one percent increase in clean energy will increase economic production by 0.38 percent respectively. The F value is significant which is indicative of the overall significance of the model and R^2 also represents that independent variables explain the variations in GDP by 65 percent of the time. The remaining variations can be accredited to other variables ignored for parsimony under the ceteris paribus assumption. The values of the variance inflation factor (VIF) for all the independent variables are less than 10 implying that these variables can be used as independent variables without the potential problem of high multi-co linearity.

Also, it is clear for drawing important implications; clean fuels are of paramount significance in the economy of China. These findings are in accordance with the findings of Nawaz and Shakeel 2023

Figure 1

Estimated Residuals



It is nevertheless clear that the magnitude of clean energy is much smaller as compared to labor implying that there is more space and scope for clean energy in production growth. The importance of capital is found insignificant albeit all these variables are significant in the long run convergence of the model, ceteris paribus. The estimated residuals from the long-run equilibrium equation in Figure 1 also demonstrate that they are stationary as depicted in the graphs.

Granger Causality Test

For the sake of uncovering the direction of causality, the present study uses the approach mentioned in the methodology section. Notwithstanding, the estimation is based on VECMs-based causality models. Thus, it is a combination of both short-run and long-run causal analysis in the proposed model. The direction of causality corroborates that there is a one-way causal connection between clean energy towards economic production but not vice versa.

Likely, the findings indicate the evidence of a two-way or feedback causal connection between clean energy and economic production (See Table 6).

Table 6

Short Run		Long Run	
	y	e	All
y	1	3.47**	6.95**
	----	(0.06)	(0.07)
e	1.47	1	16.0*
	(0.22)	---	(0.00)

** and ** denote the significance of coefficients at 5% and 10% levels of significance.*

The computed estimates of causal connection have been segregated into short run and long run. There is clear evidence that labor, capital, and clean energy are causing economic production in the long run. Also, economic production with labor and capital is causing clean energy in the long run. Thus, these discoveries of the direction of causal connection are the corroboration of a feedback hypothesis of energy in China. Thus, it is inferred that clean energy has a positive effect on economic production and the growth of production also causes to increase in the consumption of clean energy. Therefore, China should focus on developing clean energy for more sustainable economic production. The outcome implies that clean energy cannot be ignored for the economic growth in China. By and large, the global indication of the Feedback Hypothesis may be an indication that sustainable production needs a significant structural transformation of nations, considering their dependency and intensity on energy and fossil fuels

Shakeel, 2020. Notwithstanding, the presence of feedback hypothesis with clean fuels is pertinent to future energy policy considering recent environmental concerns in China.

Conclusion and Implications

Clean energy and economic production are a hot topic of the debate for a more sustainable production and environment. The present study employs a production function approach by using clean energy as a factor of production and therein provides data-based evidence on the connections between clean energy and economic production, ceteris paribus. The empirical outputs of the proposed model with their due aspects both theoretically and methodologically corroborate that there is a signal of a long-sighted equilibrium link among output, labor, and capital, with clean energy. Likewise, the lagged estimates corroborate that the clean energy augmented framework has a sustainable convergence system. This implies that clean energy is pivotal in the long-run dynamics of real output in China. Also, in the short to medium run, the error correction indicates that clean energy with labor and capital are significant contributors to the output of the country. This implies that energy policy options could be enriched with more clean fuels by improving the legacy infrastructure including capital and labor for production. Specifically, the elasticity of clean energy is found to be 0.38 percent indicating the role of clean energy in economic production. This also means that there is potential for these clean fuels to be further enhanced in the production and therein more production of clean energy sources for stable output in China.

There is corroboration of causal association from labor, capital, and clean energy towards economic production and vice versa. Thus, there is evidence of a feedback association, and it is found that there is a unidirectional causal association between clean energy towards production growth in the short run as well indicating a growth hypothesis. These findings imply that the country should focus on developing clean energy sources for sustainable economic and environmental concerns. Furthermore, there is a requisite to supply uninterrupted provision of energy by reducing the supply-demand gap for energy.

The work presents the potential of clean energy to improve the environment and production in China. The findings are nonetheless significant for policy consideration. Notwithstanding, the study provides guidelines for the sustainable growth path of the country, yet it is confined with respect to the use of other variables and regions. However, it is declared that the present study uses data till 2020 due to the availability of all data sets till this year, and therefore, post-COVID period analysis can be covered in future work therein confinement of the paper.

The present study can be extended by using other economic variables like trade etc. for future work on the subject. Also, there are different econometric methods that could be used to cater to the need for a policy question related to clean energy in China and other regions as well.

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