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Impacts of COVID-19 pandemic on renewable energy production in China: transmission mechanism and policy implications

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ABSTRACT
The renewable energy industry, in particular, has experienced an immense amount of pressure that has stemmed from the novel COVID-19 pandemic. This study, however, investigates the renewable energy production initiatives that have taken come into place as a reaction to the COVID-19 pandemic, using a time series data of China in particular. The study uses the robust ARDL bounds testing approach in order to get sound parameter estimates. The findings of the study reveal that COVID-19 pandemic has significantly reduced the renewable energy production in China, both in the short and long run. In addition to this, the GDP and trade tend to positively impact the incidence of renewable energy production in the wake of the Covid-19 pandemic. In the same context, it has been observed that the energy price has a significant and negative impact on renewable energy production, particularly in the long-run, during the pandemic period. Keeping these observations in consideration, it can be asserted that the government should ideally adopt a short-term policy, while mid-term and long-term action plans should be formulated, so as to achieve the renewable energy targets in the future. In this regard, the research implications and future directions have thoroughly been discussed in the paper.

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1. Introduction

Since December 2019, which marked the start of the COVID-19 pandemic in China, the disease has caused vast destruction around the globe. As a result, the emergency status of this highly infectious disease has required critical and drastic responses from WHO, as well as national and local governments, so as to fight the unprecedented universal health disaster (Hoang et al., 2021). In order to stop the spread of the disease, various lockdowns have been imposed at local, regional, and national levels, which have affected at least up to 30 percent of the worldwide population (Mirza

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et al., 2020 and Lai et al., 2020). Consequently, during these lockdowns, the limited social interactions and movements led to complete shutdown and/or temporary closure of 80 percent of the businesses around the globe. These have then resulted in economic recession and decline in both the production and consumption of goods and services (Chen et al., 2020; Mirza et al., 2020; and Hoang et al., 2021). As a result, the slower speed of production and economic activities have led to a substantial decline in energy demand, that have in turn influenced the utilisation of renewable energy production and consumption, and also clean energy resources. In this regard, the International Energy Agency (2021) reported that the worldwide energy demand was demolished by 3.8 percent in the first quarter of 2020, as compared to the first quarter of 2019. That decrease in the worldwide energy demand that occurred due to the COVID-19 pandemic happened to be seven times larger than the effect of the 2008 financial crisis (Yarovaya et al., 2020). Renewable energy production and consumption have been heavily influenced by the novel Corona virus pandemic. A severe decline in the economic activities has caused some colossal interruptions in the renewable energy productions, while the shortage of financing for investments in renewable energy production from government sectors and markets has also raised grave concerns among the investors (Rizvi et al., 2020 and Karmaker et al., 2021).

Moreover, the reduction in worldwide energy demand due to COVID-19 pandemic lockdowns has also affected renewable energy investments. Meanwhile. The government's sectors shifted their incentives towards COVID-19 disease relief efforts (Birol, 2020). The decline in the worldwide energy market led to financial loss in renewable energy businesses. Most specifically, the unexpected decline in production led to serious disruptions in worldwide renewable energy production (Ivanov & Dolgui, 2021). Additionally, the lack of federal and state renewable energy incentives is harmful to renewable energy's current and future development (Eroğlu, 2021). The closure of various wind tribune manufacturing plants due to the COVID-19 pandemic has harmfully affected renewable energy production (McPhee et al., 2020; Susskind & Vines, 2020). Similar adverse effects have been detected in the solar industry, which recorded a serious downfall in renewable energy production. Due to the COVID-19 pandemic, most workers furloughed and lay off the solar energy sector. Various potential solutions have been adopted to alleviate these issues that are faced by the renewable energy production sector (Jin, 2020). The COVID-19 pandemic hindered the worldwide economy, particularly the energy sector (Abu-Rayash & Dincer, 2020). Disease controlling measures such as close down of international borders, restrictions on all kinds of travelling, and conversion to remote working and learning have significantly restricted the usage of major forms of transportation and vehicles (Elavarasan et al., 2020). Indeed, a larger share of renewable energy production coming from Africa, Southeast Asia, Japan, China, the US, and the EU has progressively extended the share of renewable energy resources. Since the start of the COVID-19 pandemic, based on the scale and length of disease control measures, the impact on the energy sector might vary across various world economies. For instance, small-scale restrictions in Japan and South Korea result in around a 10 percent reduction in energy demand. In contrast, China adopted higher levels of restrictions and well-organised lockdowns that led to an approximately 15 percent reduction in

China's weekly-based energy demand. European countries documented major heaves in the number of deaths and infections and opted for complete lockdowns in various economies that resulted in an approximately 17 percent downfall in weekly energy demand. International Energy Agency reported that in 2020 worldwide oil production was anticipated to reduce by 9 percent in comparison to the level achieved in 2012. As in the past year, around the globe, the main coal-fired power plants experienced a 10 percent reduction in output, and consumption of electricity has reduced by 5 percent, the production of coal has decreased by 8 percent.

In response to the temporary reduction in major economic and production activities in China, coal production was seriously influenced by the unexpected reduction in energy demand. Alongside the economic effects of these lockdown measures, the intensified investment concerns and risks over the thriving worldwide economic downfall in response to a reduction in energy demand have challenged renewable energy investors and developers as well (Susskind & Vines, 2020). Considering the European Union's nationally binding 2020 renewable energy targets, the decreasing levels of energy demand result in reducing incentives for member countries to invest in new projects for energy production and slow down the earlier attained progress (Santiago et al., 2021). The experts have identified various influences of the COVID-19 pandemic on renewable energy production and consumption. On one side, the reduction in production costs and easy accessibility of power systems have enabled renewable energy sector demand development. (Khan et al., 2020) study reported that foreign trade plays a significant role in stimulating renewable energy utilisation. Moreover, the investment in sustainable and clean energy projects improves the environmental quality and recovers the perception of international trading partners for environment-friendly sustainability and practice (Khan et al., 2021). Additionally, despite the increase in demand for renewable energy, disturbances to financial arrangements and supply chains have led to a reduction in the instalment rate of projects in the long run. Although Germany is among the leading member of renewable energy producers around the world, the country is also facing a reduction in coal production and elimination in energy structure. The overall reduction in energy demand has destructively influenced the pricing schemes for carbon trading and renewable energy production. Subject to these negative effects of the COVID-19 pandemic, renewable energy policies face an ambiguous future because of high volatility in economic and political conditions.

From the above discussion, it is confirmed that economic activities and energy demand are closely interlinked. Hence, the policy measures adopted in the energy sector during the COVID-19 pandemic also influence renewable energy production and consumption. The existing literature has widely explored the impact of the COVID-19 pandemic on the energy sector but the impact on renewable energy production is still unexplored. To fill this vacuum present study will provide evidence on the current changes in renewable energy production due to the COVID-19 pandemic in China. This study has also practical contributions in the context of literature. This study brings its focus to the renewable energy sector at the time of COVID-19. This study can help authorities and energy regulators endorse timely policies based on empirical analyses. The results are expected to enrich the fancy literature on renewable energy consumption. This study has provided new insights and pathways to the green economy. This current study also contributes to the green energy domain by examining the connection between the COVID-19 pandemic on renewable energy production. This study has identified renewable energy production-related issues, lessons, transmission channels, and emerging opportunities for China. The study will adopt the ARDL approach to investigate the impact of the COVID-19 pandemic on renewable energy production. The findings of the study will help policy-makers in designing such energy policies that will enhance renewable energy generation, hence environmental quality improves.

The organisation of the study is as follows. The organisation of the study is as follows. The next section is a reported literature review. The model and methods are described in section three. In section four, we provide the results and conclusion in section five.

2. Literature review

To date, various environmental, economic, and social advantages have been recorded for using renewable energy. In addition to solar and wind energy, biogas is also an essential form of renewable energy which also has many ecological benefits. The increased production of renewable energy sources, including solar, wind, and biogas, may have many positive impacts on the atmosphere such as a significant decline in nutrient discharge and greenhouse gases (Umar et al., 2021a,b). Moreover, the investment and operational costs are also not that big. Similarly, Ikram et al. (2020) also highlighted that renewable energy consumption helps reduce CO2 emissions significantly. They also recorded some additional benefits in the form of higher availability of energy and improved energy efficiency. In order to achieve sustainable development and environment countries needs to invest more in renewable energy sectors and also allocate more funds to the research and development activities that helps to produce more renewable energy (Zafar et al., 2019). However, there are many barriers that can affect the supply chain of renewable energy, including technology, finance, and an unexpected shock-like pandemic. Against this backdrop, several studies in recent times tried to find the factors that have disrupted the production of renewable energy, particularly, in the presence of COVID-19 pandemic. For instance, Tsao and Thanh (2021) pointed out an optimisation model for providing financial services such as bank and trade credits in the renewable energy sector. They observed that both bank and trade credits if used prudently can stimulate the production of renewable energy (Ji et al., 2021 and Naqvi et al., 2021). Some feed-in tariff strategies also proved beneficial for the technology development in the renewable energy sector on the basis of diverse programming models, like statistical, dynamic and network models (Hosseini, 2020 and Pradhan & Ghose 2020). Apart from technological and financial hindrances, the production of renewable energy can be halted because solar and wind energy largely depends on local weather. Consequently, the incorporation of renewable energy into the grid presents threats to the pliability of the system (Tsao and Thanh, 2020).

Some of the threats to the energy sector like the COVID-19 pandemic are uncontrollable and proved to be destructive for all sectors. Like all other sectors, renewable energy sector is affected heavily by the COVID-19 pandemic. The supply chain of renewable energy is seriously disrupted due to the large-scale closure of economic activities. At the same time, the support from the government also seemed to be missing for the renewable energy sector that has irked the developers of this energy (Karmaker et al., 2021). The reduced demand in overall energy demand due to worldwide lockdown and closure of markets also dented the need for renewable energy, thereby reducing investments in this sector. During the lockdown, governments were busy in providing relief to the poor, deprived sections of society who were greatly affected by the COVID-19 pandemic; therefore, most of the funds were directed towards the pandemic relief efforts, and not enough funds were available for energy sectors (Siddique et al., 2021). In economic terms, this is the worst ever shock to the global energy sector in the last 30 years, leaving the renewable energy sector and businesses at the risk of financial bankruptcy. Particularly, the unexpected pause in the supply chain has caused significant interruptions in the international renewable energy production line (Ivanov & Dolgui, 2021). Due to the financial pressures of the relief activities, most of the governments did not provide any incentives to the renewable energy sector for its current and future development (Eroğlu, 2021). The closure of various manufacturing plants of wind turbines is an excellent example of how badly pandemic has affected the renewable energy sector (Zhang et al., 2021). For instance, it is predicted that global wind energy production will fall by 4.9 GW globally. Moreover, the wind power plants in North Dakota faces closure after COVID-19 pandemic.

On the other side, the situation is not very conducive as far as the production of solar energy is concerned. The demand for solar energy also reduced by 28% in 2020, which is another example of the worst effects of a pandemic on the clean energy sector (Hoang et al., 2021). On one side the production of solar energy is disrupted due to the COVID-19 pandemic on the other side the workers working in this sector lost their jobs during this pandemic. The same survey also pointed out a few other problems for solar energy which include delays in construction, supply chain and equipment, permission, and customer attainment. Apart from these problems, the rate of cancellations regarding solar energy orders jumps to 19% and the rate of job delay jumps to 53%. Tim (2020) highlighted that in the USA a high proportion of people were laid off in the solar energy sector during the pandemic. The supply chain of the renewable energy sector is also seriously affected by the COVID-19 pandemic. If the incentives are to be taken away from the renewable energy sector, there will be a massive reduction in the production of renewable and non-renewable energy. The prices of electricity in European economies also dropped due to a massive decline in the demand for overall energy. This fact is also supported by the report from ICIS, confirming an enormous decline in the demand for electricity consumption in the countries like Italy and France that were seriously affected by the pandemic.

3. Model, methods, and data

COVID19 is a core issue of each economy. The COVID-19 pandemic has hit renewable energy production, supply chains, and businesses and severely delayed the sustainable energy transition. Deshwal et al. (2021) noted that the COVID-19 pandemic has a significant impact on the economic renewable energy sector. Renewable energy projects are more sensitive to the COVID pandemic (Tsao and Thanh 2021). Thus, we seek to identify the impact of the COVID-19 pandemic on renewable energy production. Hence, the baseline looks as follows:

$$REP_t = \beta_0 + \beta_1 COVID19_t + \beta_2 GDP_t + \beta_3 Price_t + \beta_4 Trade_t + \varepsilon_t \quad (1)$$

The dependent variable is renewable energy production that is a proxy of nuclear-generated electricity and hydroelectric electricity. COVID19 is a set of main variables that include COVID19 confirmed cases and COVID19 deaths. Lastly, a set of control variables that includes GDP per capita (GDP), energy price (Price), and trade openness (Trade). The above model (1) is a long-run model and only provides the long-run estimates. To obtain the short-run results, we need to reformulate the above model in an error correction specification as shown below:

$$\Delta REP_t = \beta_0 + \sum_{k=1}^{n1} \beta_{1k} \Delta REP_{t-k} + \sum_{k=0}^{n2} \beta_{2k} \Delta COVID19_{t-k} + \sum_{k=0}^{n3} \beta_{3k} \Delta GDP_{t-k} + \sum_{k=0}^{n4} \beta_{4k} Price_{t-k} + \sum_{k=0}^{n5} \beta_{5k} Trade_{t-k} + \gamma_1 REP_{t-1} + \gamma_2 COVID19_{t-1} + \gamma_3 GDP_{t-1} + \gamma_4 Price_{t-1} + \gamma_5 Trade_{t-1} + \varepsilon_t \quad (2)$$

Specification (2) has now taken the form of the ARDL model of (Pesaran et al., 2001). This method is considered superior as compared to most of the other techniques. First, it provides short and long-run estimates only by estimating a single equation (2). Certainly, short-run results are revealed in the coefficient estimates linked to the Δ variables. The long-run results are represented from approximations of $\gamma_2 - \gamma_5$ normalised on γ_1. In order to prove the validity of the long-run estimates, (Pesaran et al., 2001) suggest a cointegration test that confirms the combined significance of lagged level variables (Bahmani-Oskooee et al., 2020; Usman et al., 2021). The process is similar to the procedure of the F-test; however, (Pesaran et al., 2001) developed new critical values for this test. Another advantage of this method is that we don't need to worry about the pre-unit root testing because this method can account for the integrating properties of the variables, i.e., we can include a mixture of I(0) and I(1) variables. Moreover, the technique provides efficient results even if the sample size is small. Lastly, the inclusion of a short-run dynamic process provides feedback effects among the variables; consequently, control the endogeneity and multicollinearity (Pesaran et al., 2001).

The objective of the study is to investigate the impact of the COVID-19 pandemic on renewable energy production in the case of China. For that purpose, the dependent variable is measured by renewable energy production that is generated by nuclear and hydroelectric power. While COVID-19 confirmed cases and COVID-19 deaths are taken as independent variables in the analysis. Table 1 delivers a detailed discussion about definitions and sources of variables. The study incorporated few other control variables in the analysis. These are GDP, price level, and trade. Where GDP

Table 1. Definitions and data sources.

Variables	Definitions	Data sources
Hydro	Renewable energy production-Hydro (kWh bn)	National Bureau of Statistics
Nuclear	Renewable energy production-Nuclear (%)	National Bureau of Statistics
COVID-cases	COVID-19 confirmed cases	WHO
COVID-deaths	COVID-19 deaths cases	WHO
GDP	Gross Domestic Product, Nominal, Undjusted, Domestic Currency	IMF
Price	Consumer Prices index, all items	IMF
Trade	Exports and imports of Goods and Services, Nominal, Unadjusted, Domestic Currency	IMF

Source: Author's Estimation.

is measured in nominal unadjusted domestic currency. CPI is used to measure price level, and trade is measured by the sum of exports and imports of goods and services in nominal unadjusted domestic currency. The high levels of GDP are generally improved infrastructures of renewable energy production, while the price of traditional energy sources is also encouraging the consumption and production of renewable energy (Bamati and Raoofi 2020). Foreign trade has also increased the renewable energy production of China (Chen et al., 2019). GDP, energy price, and trade are the main drivers of renewable energy production, so we have included them in the model. Data on COVID-19 cases and COVID-19 deaths is extracted from 'WHO,' The data on renewable energy production is collected from the national bureau of statistics, while the data on all control variables are retrieved from the IMF.

4. Results and discussion

Before executing regression analysis, it is imperative to check the stationarity properties of data. The study implied Augmented Dickey-Fuller (ADF) and Philips Perron (PP) unit root tests for that purpose. The empirical outcomes of ADF and PP tests are given in Table 2. The outcomes of both tests reveal that COVID-cases and COVID-deaths both variables are level stationery, however, all other variables are first difference stationary. None of the variables holds a second difference stationary property. Based on these results, it is feasible to apply the ARDL approach for empirical investigation. Table 3 reports long-run and short-run ARDL estimates of renewable energy production for basic models and robust models. The first panel delivers short-run estimates of basic and robust models; the second panel demonstrates long-run estimates and the last panel provides findings of some important diagnostic tests required for validation of empirical outcomes of ARDL models.

The long-run estimates of basic models reveal that COVID-cases have a significant and negative impact on nuclear energy, revealing that a 1 percent increase in COVD-cases results in a 1.991 percent reduction in nuclear energy. The long-run coefficient estimates of robust models demonstrate that COVID-deaths cases had a significant and negative impact on hydroelectric power energy, revealing that a 1 percent increase in COVID-deaths leads to a 0.471 percent reduction in hydroelectric power energy. However, COVID-cases have no significant impact on hydroelectric power

Table 2. Unit root tests.

	ADF			PP		
	I(0)	I(1)	Decision	I(0)	I(1)	Decision
Nuclear	−1.655	−4.235***	I(1)	−1.475	−2.687*	I(1)
Hydro	−1.896	−2.756*	I(1)	−1.544	−2.987**	I(1)
Cases	−8.325***		I(0)	−8.062***		I(0)
Deaths	−3.302**		I(0)	−5.655***		I(0)
GDP	−0.454	−3.987***	I(1)	−0.455	−2.756*	I(1)
Price	−2.201	−3.452**	I(1)	−1.897	−3.456**	I(1)
Trade	−1.325	−2.785*	I(1)	−1.452	−2.750*	I(1)

Note: ***p < 0.01; **p < 0.05; and *p < 0.1.
Source: Author's Estimation.

Table 3. ARDL estimates of renewable energy production.

	Basic models				Robust models			
Variable	Coefficient (1)	t-Stat	Coefficient (2)	t-Stat	Coefficient (3)	t-Stat	Coefficient (4)	t-Stat
Short-run								
D(CASES)	−1.442	1.540	−0.987**	2.054				
D(DEATH)					−2.803	0.111	−0.348	0.764
D(DEATH(-1))					2.087	1.525		
D(GDP)	1.024***	2.980	2.740**	2.072	2.417	1.426	1.308	1.242
D(GDP(-1))	−4.355*	1.805	3.977***	2.741	−7.586*	1.699		
D(PRICE)	2.591	1.355	0.993	0.240	2.627	1.151	2.679	1.013
D(PRICE(-1))	1.787**	2.130	−2.728***	6.637	1.032	1.163	1.730**	1.975
D(TRADE)	1.938***	2.768			1.546**	2.155	5.242	0.891
D(TRADE)					2.340	0.708	6.291**	2.177
Long-run								
CASES	−1.991*	1.842	−1.224	1.022				
DEATH					−1.430	0.571	−0.471***	2.685
GDP	1.980***	2.590	1.330*	1.765	1.481***	2.681	1.334***	4.216
PRICE	−2.123***	2.873	2.252	0.261	2.414	1.384	1.396	0.766
TRADE	2.474	0.299	2.236*	1.728	1.630	0.378	2.782***	4.097
C	11.11***	2.263	8.928*	1.683	−10.61	0.069	7.375***	3.283
Diagnostics								
F-test	7.120***		9.357***		4.879***		5.818***	
ECM(-1)	−0.356***	4.895	−0.334*	1.689	−0.456***	4.069	−0.504***	3.153
Adj-R2	0.954		0.964		0.922		0.932	
LM	1.235		1.357		1.326		0.987	
BP	0.962		0.632		0.321		0.954	
RESET	0.004		1.366		0.329		0.356	
CUSUM	S		S		S		S	
CUSUM-sq	S		S		S		S	

Note: ***p < 0.01; **p < 0.05; and *p < 0.1.
Source: Author's Estimation.

energy in the basic model, and COVID-deaths reported no significant impact on nuclear energy in the robust model in the long run.

This finding is also consistent with Hosseini et al. (2021), who noted that COVID-pandemic has hurt the renewable energy manufacturing facilities, supply chains, and even slowed down the transition to renewables. The simple meaning of this outcome is that COVID disturbs the new uninstall renewable energy projects. This finding is compatible with Tsao and Thanh (2021), who noted that COVID19 disrupts the supply and demand of renewable energy. This unpleasant situation has an adverse effect on renewable energy projects.

Similarly, trade-related renewable energy technology is closed because of the global shutdown. COVID negatively impacted the renewable energy sectors in three different ways. Lockdown policies restrict economic activities by increasing uncertainty which reduces investments in the renewable industry. Similarly, the Chinese government has sacrificed a significant amount of its GDP to attain a green and clean economy. In response of COVID, China diverted financial resources from the goals of climate mitigation to health. This study is related to Shah et al. (2021) who reported the same transmission channels between COVID-19 and renewable energy production. The high producers of renewable energy have also experienced a slowdown in clean energy generation projects. A possible reason is that authorities have one concern that is health-related projects by dropping energy-related projects.

Findings also infer that COVID-19 has reduced oil prices by dropping renewable energy production. Similarly, the shutdown of industrial sectors due to the tight lockdown has caused low demand for energy which has fallen by renewable energy generation in China. Also, investment in the renewable energy sector has been decreasing by investors due to high economic uncertainty. Renewable energy enterprises are also credit constants in the COVID pandemic. At the same time, financial institutions cannot properly work in a pandemic. The performance of supporting factors of renewable energy generation is also deprived in COVID. This infers that renewable energy production is reducing in China.

The study has incorporated the role of GDP, price level, and trade as control variables in the regression analysis. The GDP variable reported a significant positive impact in all models, confirming that both types of renewable energy production rise in the long run due to an upsurge in GDP. Results demonstrate that in response to 1 percent rise in GDP, nuclear rises by 1.980 percent in the basic model and 1.481 percent in the robust model, and hydroelectric power energy increases by 1.330 percent in the basic model and 1.334 percent in the robust model. This finding is similar to that of Bamati and Raoofi (2020) who show that GDP has a favourable impact on renewable energy production. Price variable has reported a significant and negative impact on nuclear energy in the long-run in basic ARDL model only. Findings show that a 1 percent upsurge in price level results in reducing nuclear energy by 2.123 percent. In the long run, the trade effect is significant and positive on hydroelectric power energy in the basic and robust models. This finding is also consistent with Chen et al. (2021), who noted that foreign trade can play an important role in the renewable energy sector because it can lead to the transferring of renewable energy technology. The results show that a 1 percent increase in the inflow of trade leads to increased hydroelectric power energy by 2.236 percent in the basic model and 2.782 percent in the robust model.

The short-run findings of basic model infer that COVID-cases has no significant impact on nuclear energy, in contrast, it exerts a significant negative impact on hydroelectric power energy in the short run. The coefficient estimate reveals that in response to a 1 percent rise in COVID-cases, hydroelectric power energy reduces by 0.987 percent. The findings of the robust model reveal that the COVID-deaths variable has no significant influence on both types of renewable energy production in the short run. In the short run, GDP significantly and positively increases both types of renewable energy production in basic models, but in robust models, this variable has no significant influence on renewable energy

Table 4. Results of causality test for China.

Null Hypothesis:	F-Stat	Prob.		Null Hypothesis:	F-Stat	Prob.	
CASES→NUCLEAR	3.113	0.079	Yes	CASES→HYDRO	0.159	0.854	No
NUCLEAR→CASES	0.001	1.000	No	HYDRO→CASES	2.377	0.132	No
DEATHS→NUCLEAR	2.244	0.146	No	DEATHS→HYDRO	0.444	0.651	No
NUCLEAR→DEATHS	0.444	0.651	No	HYDRO→DEATHS	7.613	0.007	Yes
GDP→NUCLEAR	1.818	0.201	No	GDP→HYDRO	0.735	0.499	No
NUCLEAR→GDP	1.595	0.240	No	HYDRO→GDP	0.664	0.531	No
PRICE→NUCLEAR	0.016	0.985	No	PRICE→HYDRO	0.003	0.997	No
NUCLEAR→PRICE	0.372	0.697	No	HYDRO→PRICE	0.911	0.426	No
TRADE→NUCLEAR	3.058	0.082	Yes	TRADE→HYDRO	1.295	0.307	No
NUCLEAR→TRADE	0.132	0.878	No	HYDRO→TRADE	1.160	0.344	No
DEATHS→CASES	1.539	0.251	No	DEATHS→CASES	1.539	0.251	No
CASES→DEATHS	21.54	0.000	Yes	CASES→DEATHS	21.54	0.000	Yes
GDP→CASES	2.966	0.087	Yes	GDP→CASES	2.966	0.087	Yes
CASES→GDP	8.982	0.004	Yes	CASES→GDP	8.982	0.004	Yes
PRICE→CASES	0.808	0.467	No	PRICE→CASES	0.808	0.467	No
CASES→PRICE	6.762	0.010	Yes	CASES→PRICE	6.762	0.010	Yes
TRADE→CASES	2.211	0.149	No	TRADE→CASES	2.211	0.149	No
CASES→TRADE	1.627	0.234	No	CASES→TRADE	1.627	0.234	No
GDP→DEATHS	10.587	0.002	Yes	GDP→DEATHS	10.587	0.002	Yes
DEATHS→GDP	4.170	0.040	Yes	DEATHS→GDP	4.170	0.040	Yes
PRICE→DEATHS	16.75	0.000	Yes	PRICE→DEATHS	16.75	0.000	Yes
DEATHS→PRICE	3.854	0.049	Yes	DEATHS→PRICE	3.854	0.049	Yes
TRADE→DEATHS	17.10	0.000	Yes	TRADE→DEATHS	17.10	0.000	Yes
DEATHS→TRADE	2.925	0.089	Yes	DEATHS→TRADE	2.925	0.089	Yes
PRICE→GDP	1.440	0.272	No	PRICE→GDP	1.440	0.272	No
GDP→PRICE	1.059	0.375	No	GDP→PRICE	1.059	0.375	No
TRADE→GDP	3.899	0.047	Yes	TRADE→GDP	3.899	0.047	Yes
GDP→TRADE	1.644	0.231	No	GDP→TRADE	1.644	0.231	No
TRADE→PRICE	1.550	0.249	No	TRADE→PRICE	1.550	0.249	No
PRICE→TRADE	1.556	0.248	No	PRICE→TRADE	1.556	0.248	No

Note: ***$p < 0.01$; **$p < 0.05$; and *$p < 0.1$.
Source: Author's Estimation.

production. Price variable recorded no significant impact on renewable energy production in all basic and robust models in the short run. In the end, trade exerts a significant and positive influence on nuclear energy production in basic and robust models, but this variable shows no influence on hydroelectric power energy in basic and robust models.

The last panel of Table 3 delivers empirical outcomes of various important diagnostic tests such as autocorrelation test, heteroskedasticity test, normality test, and stability test. F-statistics and ECM are also required for the validation of long-run cointegration among ARDL estimates. F-statistics and ECM (-1) coefficient estimates confirm that long-run cointegration associations exist among variables in all four models. The negative coefficient estimates of ECM confirm that the tendency of convergence towards equilibrium exists in all four models. There is no issue of autocorrelation and heteroskedasticity in all four models, as confirmed by LM and BP test findings. The coefficient estimates of the Ramsey RESET test reveal that all four models are normally distributed. All four models are stable, as confirmed by findings of CUSUM and CUSUM-sq tests. Finally, the results of Granger causality are reported in Table 4. To save space, we only discuss the results of Granger causality between COVID and renewable energy production. From Table 4, we gather that one-way causality runs from nuclear and hydro →deaths cases in the base and robust model.

5. Conclusion and implications

There are many sources of renewable energy, particularly wind, solar, water, and biomass which provide renewable energy production without giving rise to any pollution. The national energy policies and strategies of China are aimed at involving a substantial contribution of renewable energy in the mixture of electricity generation. China has been faced many challenges in the generation of renewable energy production. COVID-19 is considered as one of the foremost economic challenges that not only the Chinese government but also most governments across the globe have failed to overcome to era. Renewable energy production is safe, convenient, affordable, and has zero carbon emissions into the atmosphere.

Findings of the study reveal that COVID-cases negatively influence nuclear energy in the basic model. Moreover, in the case of the robust model, COVID-deaths report a negative influence on hydroelectric power energy confirming that an increase in COVID-19 death leads to a significant decline in hydroelectric power energy in the long-run. The short-run findings reveal that COVID-cases negatively affect hydroelectric power energy in the basic model. In the case of control variables, the GDP variable exerts a positive impact on renewable energy production in all regression models in the long-run, however, GDP positively influences renewable energy production only in basic models in the short-run. Energy price variables negatively affect renewable energy production, however, trade positively and significantly influence renewable energy production in the long-run and short-run.

The focus on green growth and lower carbon needs a central space in the policy and planning practices in China. The Chinese government should accelerate renewable energy production by dropping conventional energy production, suffering huge losses due to reduced energy output and lower prices. China can change the energy structural shift from high carbon emissions energy to zero carbon emissions energy in paramedic. China should increase public-private participation in renewable energy generation projects and as it can be a crucial driver for job creation and economic recovery. Some financial relief measures have been taken to alleviate the COVID-19 impacts on renewable energy development. Authorities should improve the supporting factors of renewable energy generation. Further government efforts to restore the energy supply network are also necessary required in China. The COVID-19 pandemic has simulated low-carbon infrastructure to lower pollution, thus policymakers should introduce new introduce carbon-neutral policies.

This study has limitations. This work is limited to only China by ignoring the other world's major producers of renewable energy production. A similar analysis is also conducted for other producers of renewable energy. The author's theoretical implications can also be drawn about the future of renewable energy generation. Future research may focus on using COVID-pandemic trends to develop more sustainable and reliable policies on renewable energy development for other economies. Future work also assesses the direct and indirect transmission channels of the COVID-19 pandemic on renewable energy production. The author should also scrutinise the impact of COVID-19 waves on renewable energy projects and compares the results. The future study contributes to the green growth domain by investigating the connection between the COVID-19 pandemic and the clean energy market.

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