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Economic and ecological complexity in the wake of COVID-19 pandemic: evidence from 60 countries

Jinrong Jia^a, Muhammad Khalid Anser^b, Michael Yao-Ping Peng^c,
Abdelmohsen A. Nassani^d, Mohamed Haffar^e and Khalid Zaman^f

^aParty School of Lianyungang Municipal Committee of C.P.C, Lianyungang, Jiangsu, China; ^bSchool of Public Administration, Xi'an University of Architecture and Technology, Xi'an, China; ^cSchool of Economics & Management, Foshan University, Foshan, China; ^dDepartment of Management, College of Business Administration, King Saud University, Riyadh, Saudi Arabia; ^eDepartment of Management, Birmingham Business School, University of Birmingham, Birmingham, UK; ^fDepartment of Economics, University of Haripur, Haripur Khyber Pakhtunkhwa, Pakistan

ABSTRACT

The coronavirus disease 2019 is a deadly disease that globally infected millions of people. It enormously increases economies national healthcare bills and death tolls that deprive the global world. The negative environmental externality further strains the country's healthcare sustainability agenda, causing to decline in global income. The study evaluates the different socio-economic and environmental factors to assess ecological complexity in a large, cross-country data set that includes 60 countries. The study used the following variables for estimation, i.e., coronavirus cases, cost of carbon emissions, per capita economic growth, foreign direct investment inflows, and population growth. Markov Switching Regression, VAR Granger causality and variance decomposition analysis applied on the given dataset. The results show that the COVID-19 cases have a rebound effect on environmental quality. Economic activities started after a lifted lockdown, and unsustainable production and consumption led to a deteriorating natural environment. The U-shaped relationship is found between carbon pollution and per capita income. On the other hand, the inverted U-shaped relationship is found between coronavirus cases and carbon pollution. The foreign direct investment inflows and population density increases carbon pollution. The study concludes that stringent environmental policies and incentive-based regulations help to minimize coronavirus cases and mitigate carbon pollution.

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1. Introduction

The Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) virus strain spread worldwide in late December 2019 and spread out to more than 200 countries

CONTACT Khalid Zaman  khalid_zaman786@yahoo.com

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and territories relatively in a shorter period. The transmitted diseases called coronavirus diseases 2019 (COVID-19) was coined by WHO as a 'pandemic' in March 2020. The disease spread out from the Hubei province of Wuhan, China, and penetrated the global world. The data is readily available at the WHO and other databases, which shows the high infected cases and deaths by coronavirus disease in the USA, followed by India, Brazil, Russia, and the UK (Worldometer, 2021).

Global warming is the volatile factor that is increased by the greater stock of carbon emissions in the atmosphere. International organizations and environmental protection agencies significantly reduce such emissions through sustainable and cleaner technologies (Shao et al., 2020). The relationship between carbon emissions and economic growth is widely evident in the environmental science literature that proclaims that economic growth is somehow responsible for increasing carbon emissions at certain threshold levels. In contrast, after reaching its destination, economic growth moves towards smart and green technologies that help to reduce carbon emissions. This relationship is mainly inverted U-shaped, called Environmental Kuznets Curve (EKC), but it also depends on the country's sustainable efforts to reduce such emissions (Suki et al., 2020). The government's easy economic and environmental policies further strain the natural environment through more significant inbound FDI that pollute the environment. This phenomenon is widely understanding with the 'Pollution Haven Hypothesis (PHH)'. Tight government regulations, either formal or informal, help reduce carbon emissions (Sadik-Zada & Ferrari, 2020; Wang et al., 2019). Moreover, the pollution exacerbated by increasing population growth, affluence, and technology, the I-PAT hypothesis, needs to be reduced through human capital formation, sustainable economic growth, and cleaner technologies (Chontanawat, 2019). These hypotheses are under investigation in this study with some modifications that we called up with the 'alternative' hypothesis. The study used the EKC hypothesis, PHH, and I-PAT hypothesis. It extended these hypotheses into alternative ones, i.e., pandemic Kuznets curve (PKC), Pandemic pollution haven (PPH) hypothesis and pandemic-population-pollution (PPP) hypothesis in a cross-section of 60 selected countries.

The study has filled the literature gap by comparing alternative and plausible environmental hypotheses during the pandemic crisis that has been less explored recently, leading to misspecified healthcare policies globally. The rise and fall in the carbon emissions per capita due to continuing per capita income of the countries are widely discussed under the central theme of 'environmental Kuznets curve (EKC)' (see, Anser et al., 2020a, 2021a; Apergis & Ozturk, 2015; Dinda, 2004; Nassani et al., 2017). In comparison, little is discussed in the pandemic crisis that has possible a rebound effect on environmental quality to increase the costs of carbon emissions globally (see, Aljadani et al., 2021; Jóźwik & Gruszecki, 2020). The study filled this gap and assessed the EKC hypothesis and pandemic Kuznets curve (PKC) in carbon cost modelling to determine viable healthcare sustainable policies across countries. The EKC hypothesis was formally analyzed by the non-linear functional relationship between per capita carbon emissions and countries' per capita income (and the square of per capita income) to find the different possible hump-shaped relationships between them. The PKC is analyzed by the relationship between carbon damages and

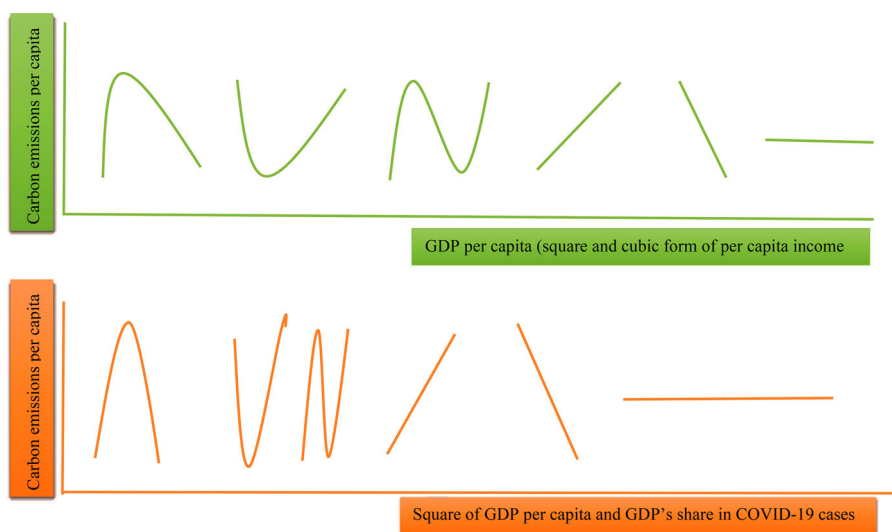


Figure 1. Different shapes of EKC and PKC hypothesis.

Source: adapted from Dinda (2004), and Aljadani et al. (2021).

the square of per capita income (and share of GDP's per capita relative to COVID-19 cases) to obtain the possible shapes across countries. Figure 1 shows the different forms of possible EKC hypothesis and PKC hypothesis for ready reference.

Figure 1 illustrated that the EKC and PKC hypotheses either confirmed the inverted U-shaped, U-shaped, N-shaped, monotonic increasing or decreasing, or flat relationship between the variables. The point of interest is that the PKC shapes have less diameter than EKC shapes because the pandemic crisis is likely short. It will be settled down after adopting strict, standardized operating procedures to control coronavirus cases. Another environmental hypothesis mainly discussed before the pandemic crisis was the 'pollution haven' (PH) hypothesis. This hypothesis accounts for dealing with foreign production in the homeland that negatively influenced the host countries' environmental quality, affecting the world by the ease of environmental regulations. Several scholarly contributions have been worked on the stated hypothesis and found some interesting findings that conclude it with the adoption of stringent environmental regulations to control dirty production (see Anser et al., 2021b; Cole, 2004; Liu et al., 2019; Nassani et al., 2019; Solarin et al., 2017; Zaman & Abd-el Moemen, 2017). The study takes an added advantage to analyze the pandemic pollution have (PPH) hypothesis by incorporating the share of FDI's relative to COVID-19 cases in the carbon cost modelling across countries. Few studies indirectly found the stated hypothesis necessary in policy formulation (see Elliott et al., 2020; Erokhin & Gao, 2020; Wang & Wang, 2020). Figure 2 shows the PH and PPH hypothesis for ready reference.

Finally, the study evaluated 'population-induced emissions' widely explored by the IPAT hypothesis in earlier studies. The IPAT hypothesis shows the emissions intensity subject to population growth, affluence, and technology (see Hishan et al., 2019; Nassani et al., 2021; Ozcan & Ulucak, 2020). In contrast, there is little evidence during the current pandemic crisis explored in this study concerning the moderation use

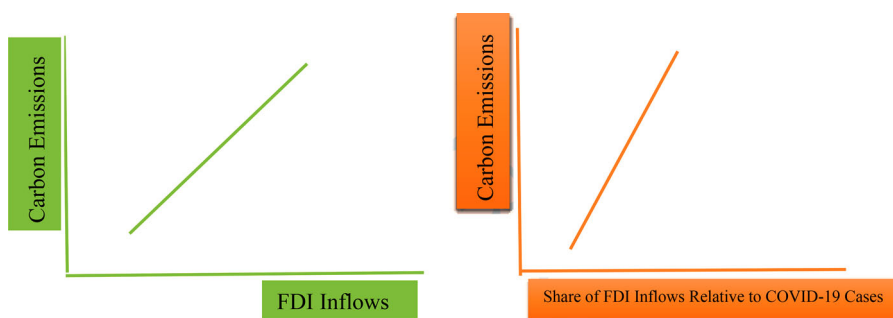


Figure 2. PH and PHH hypothesis.

Source: adapted from Cole (2004) and Elliott et al., (2020).

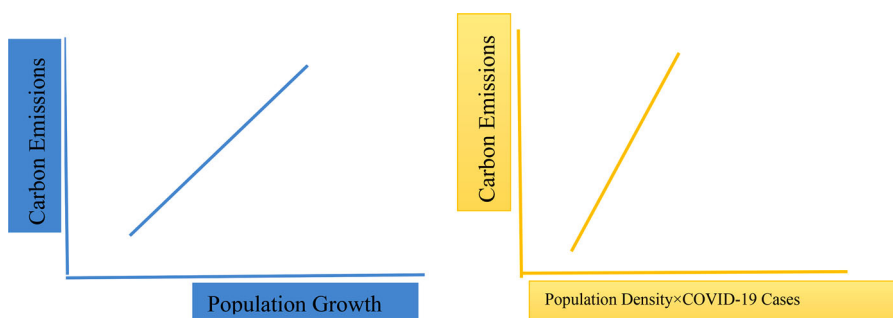


Figure 3. IPAT and PPP hypothesis.

Source: adapted from Nassani et al. (2021) and authors self-extract.

of COVID-19 cases with population density. This phenomenon is representing with the 'pandemic-population-pollution (PPP)' hypothesis. The study assumed that population compactness causes increasing COVID-19 cases and environmental destruction, thus negatively impacting countries' environmental sustainability agenda. Figure 3 shows the IPAT and PPP hypothesis for ready reference.

The current literature on the stated theme is limited; however, in the case of spreading the knowledge to the general audience, the study mentioned the following literature to quickly followed the earlier research contributions on the environmental sustainability agenda in the wake of the COVID-19 pandemic. Table 1 shows current literature on the stated theme for ready reference.

Based on the cited literature, the study presented the contribution of the study. The study is first in its nature that evaluated different alternative and plausible environmental-health hypotheses associated with the COVID-19 cases across countries. The main hypotheses include, i) pandemic Kuznets curve that follows the relationships between the square of per capita income and GDP's share in COVID-19 cases, which established the inverted U-shaped relationship between them, ii) pandemic pollution haven hypothesis refers to the situation where the share of FDI's inflows relative to COVID-19 increases the cost of carbon emissions, which ultimately affect the green growth developmental agenda globally, and iii) pandemic-population-pollution hypothesis is the amalgamation of the COVID-19 cases, population density, and carbon damages that refers the situation where the share of population density relative

Table 1. Current literature on environmental sustainability during the COVID-19 pandemic.

Authors	Factors	Results
Chakraborty and Maity (2020)	Migration, environmental safety, and prevention	COVID-19 negatively affects the globalized world that needs environmental safety and prevention strategies to reduce disease transmission from one person to another.
Zambrano-Monserrate et al. (2020)	Waste and recycling issues	COVID-19 indirectly impacts the natural environment that sabotaged the green development agenda due to the contamination of land and water, which causes the spread of contagious disease.
SanJuan-Reyes et al. (2021)	Air pollutants and health hazards	The possible correlation between air pollutants and spreading the coronavirus cases needs to reduce anthropogenic pollutants in the atmosphere.
Cheval et al. (2020)	Environmental pollution and COVID-19 cases	The disposal of sanitary consumables causes severe air pollution that negatively affects the individuals' health, possibly lead to infection with coronavirus disease.
Espejo et al. (2020)	Climatic factors	Biodegradable medical supplies should be considered for preventing the future pandemic.
Rizou et al. (2020)	Food supply chain	The food industry is affected mainly due to increase coronavirus cases, which negatively affect the food supply chain globally.
Elavarasan and Pugazhendhi (2020)	Technological advancement	Advancement in key technologies helps to restore the natural environment and control COVID-19 cases globally.
Eroğlu (2021)	Green energy sector	The renewable energy sector is primarily affected by the COVID-19 pandemic in supply chain disruption, tax imposition, and uncertainty in economic policies that lead investors reluctant to invest in the clean energy infrastructure.
Atalan (2020)	COVID-19 measures and healthcare & environmental issues	The lockdown measures significantly suppressing the COVID-19 cases while its negative effect on psychological and environmental disorders worldwide.
Kumar et al. (2020)	Symptomatic treatment and healthy immune system	Besides strict measures of COVID-19, a healthy immune system is helpful to suppress COVID-19 cases.

Source: Authors extracted from the earlier studies.

to COVID-19 cases exacerbate carbon damages to affect environmental sustainability agenda. Second, the study used different moderating and mediating factors linked with the COVID-19 pandemic to assess the magnitude of stated factors to affect air quality indicators across the countries. Finally, the study analyzed the stated hypotheses in the inter-temporal forecasting framework that helped devise future healthcare policies for developing green growth agendas. Based on the study's contribution, the study's objectives are to examine the rebound effect of the COVID-19 pandemic on carbon damages. Further, the study evaluated the non-linear relationship between per capita income and carbon damages in the wave of COVID-19 cases across countries.

Finally, the study assesses the impact of FDI's share in COVID-19 cases and population-induced COVID-19 cases in the healthcare sustainability agenda. The stated objectives need to be checked by sophisticated statistical techniques to get robust parameter inferences for devising healthcare policies across countries.

2. Data and methodological framework

The study used carbon damages (CARB_DAM, % of GNI) as a 'response' variable. In contrast, COVID-19 cases (denoted by COVID19, in numbers), GDP per capita (denoted by GDP_PC, constant 2020 US\$), FDI inflows (denoted by FDI_INF, % of GDP), and population density (denoted by POP_DEN) used as explanatory variables. Besides, the study used different moderating and mediating factors to evaluate alternative and plausible environmental hypotheses, including, i) square of GDP_PC (denoted by SQGDP_PC), ii) an interaction term of POP_DEN and COVID19 (denoted by POP_DEN \times COVID19), iii) the share of GDP_PC relative to COVID19 (denoted by GDP_PC/COVID19), and iv) the share of FDI_INF relative to COVID19 (denoted by FDI_INF/COVID19). [Table 2](#) shows the list of sample countries used in the study for ready reference.

The stated variables evaluated the following environmental hypotheses, i.e.,

- i. *Environmental Kuznets Curve (EKC) Hypothesis*: The rise and fall in the carbon damages associated with the increase and mega increase in the countries per capita income describe the EKC hypothesis (see, Anser et al., 2021b; Cheng et al., 2021; Koonthar et al., 2021). The study used GDP_PC and SQGDP_PC in the functional relationship with the CARB_DAM to evaluate the EKC hypothesis in a cross-section of 60 countries.
- ii. *Pandemic Kuznets Curve (PKC) Hypothesis*: The study assumes that doubling the GDP_PC leads to a deteriorating natural environment. Simultaneously, the share of GDP_PC relative to COVID19 would likely decrease carbon damages, leading to spending more money on healthcare resources and its infrastructure that helps move forward towards achieving the healthcare sustainability agenda globally. This phenomenon is referred to as the PKC hypothesis.
- iii. *Pollution Haven (PH) Hypothesis*: Generally, the pollution haven hypothesis describes the role of dirty polluting industries that get benefited from the ease of environmental regulations to deteriorate the natural environment, which accounts for increasing FDI inflows on the cost of carbon emissions (see Ahmad et al., 2021; Anser et al., 2020b). The study used the same concept to evaluate the PH hypothesis to observe any additional increase in carbon damages associated with the inbound FDI across countries.

Table 2. List of sample countries.

"USA, India, Brazil, Russia, UK, France, Spain, Italy, Turkey, Germany, Colombia, Mexico, Poland, South Africa, Ukraine, Peru, Indonesia, Czechia, Canada, Portugal, Chile, Romania, Belgium, Sweden, Austria, Serbia, Japan, Hungary, UAE, Jordan, Panama, Slovakia, Belarus, Malaysia, Georgia, Croatia, Azerbaijan, Bulgaria, Tunisia, Costa Rica, Lithuania, Slovenia, Kuwait, Greece, Moldova, Armenia, Guatemala, Qatar, Paraguay, Oman, Bosnia and Herzegovina, North Macedonia, China, Kyrgyzstan, Latvia, Singapore, El Salvador, Estonia, Luxembourg, Finland".

Source: Worldometer (2021).

- iv. *Pandemic Pollution Haven (PPH) Hypothesis*: The study assumes that the share of increasing FDI inflows in reducing coronavirus cases would likely increase carbon damages due to increased commercialization activities across countries. Hence, the study considers the share of FDI_INF relative to COVID19 as a mediating factor in modelling carbon emissions to confirm the PPH hypothesis across countries.
- v. *Population-Induced Emissions (IPAT) Hypothesis*: The IPAT hypothesis generally refers to the economic situation where emissions intensity changes the population growth, affluence, and technology (Tarazkar et al., 2020; Yue et al., 2020). The growth rate of population leads to increase carbon damages, which is observed in the study by using population density as a determinantal factor that sabotaged the environmental sustainability agenda worldwide, and
- vi. *Pandemic-Population-Pollution (PPP) Hypothesis*: The study assumes that population density is the causal factor in increasing the exposure of coronavirus cases; as greater the population compactness, the greater the possibility to get exposed to the contagious diseases. Hence, the study used the moderation of POP_DEN and COVID19 cases to explore the impact on carbon damages to support the PPP hypothesis.

Based on the theoretical support, the study formulated the empirical equation to explore the dynamics of COVID-19 cases and carbon damages under different moderation and mediating variables in a cross-section panel of 60 countries, i.e.,

$$\begin{aligned}
 CARB_DAM_{60,2021} &= \Gamma_0 + \Gamma_1 COVID19_{60,2021} + \Gamma_2 GDP_PC_{60,2021} + \Gamma_3 SQGDP_PC_{60,2021} \\
 &+ \Gamma_4 \left(\frac{GDP_PC}{COVID19} \right)_{60,2021} + \Gamma_5 FDI_INF_{60,2021} + \Gamma_6 \left(\frac{FDI_INF}{COVID} \right)_{60,2021} + \Gamma_7 POP_DEN_{60,2021} \\
 &+ \Gamma_8 (POP_DEN \times COVID19)_{60,2021} + \varepsilon_{60,2021} \\
 \therefore \partial \left(\frac{CARB_DAM}{COVID19} \right) &> 0; \partial \left(\frac{CARB_DAM}{GDP_PC} \right) > 0; \partial \left(\frac{CARB_DAM}{SQGDP_PC9} \right) < 0; \partial \left(\frac{CARB_DAM}{GDP_PC/COVID19} \right) < 0; \\
 \partial \left(\frac{CARB_DAM}{FDI_INF} \right) &> 0; \partial \left(\frac{CARB_DAM}{FDI_INF/COVID19} \right) > 0; \partial \left(\frac{CARB_DAM}{POP_DEN} \right) > 0; \partial \left(\frac{CARB_DAM}{POP_DEN \times COVID19} \right) > 0
 \end{aligned} \tag{1}$$

where CARB_DAM shows carbon damages, COVID19 shows COVID-19 cases, GDP_PC shows GDP per capita, FDI_INF shows FDI inflows, POP_DEN shows population density, and ε shows error term.

Equation (1) shows that COVID-19 cases would likely increase by increasing carbon damages. Simultaneously, there is likely to get a hump-shaped relationship between countries' per capita income and carbon damages across countries. Moreover, the share of countries per capita income relative to COVID-19 is expected to decrease carbon damages to support the pandemic Kuznets curve hypothesis. The inbound FDI is expected to harm the natural environment to exacerbate carbon emissions. Further, its share of COVID19 cases is likely to increase carbon damages to support the PH and PPH hypotheses, respectively. The population density is expected to establish the negative impact on carbon damages to support the IPAT hypothesis. In contrast, its moderation negatively impacts environmental pollution to support the

PPP hypothesis across countries. The following hypotheses need to be verified under carbon pandemic modelling in a panel of selected countries, i.e.,

H1: The likelihood that COVID-19 cases increase along with an increase in carbon damages across countries.

H2: The inverted U-shaped relationship is expected in a combination of different variables relative to carbon damages to support EKC and PKC hypothesis, and

H3: FDI inflows, population density, and COVID-19 cases support PH, PPH, and PPP hypotheses.

The stated hypotheses need to be checked using different statistical techniques, including the Switching regression approach, Granger causality estimates, and variance decomposition analysis for sound inferences. The Markov switching two-regime analysis helps analyze the non-linear relationship between the variables in different m-stage regime regressions. The stated modelling approach assumed many m-regression equations for each statistical analysis to check the regression parameters with 'common' factors. The dynamic relationship can be found by including the lagged dependent variable in the switching regression approach to observe the possible heteroskedasticity and serial correlation issues accordingly. The study added non-linear factors in the 'common' regression to analyze the variables' inverted U-shaped relationships. Based on the results, the study moves forward to estimate Granger causal relationship between the linear and non-linear variables resulting in an impact on carbon damages across countries. The following hypothesis need to be checked in the schematic fashion of causality, i.e.,

Postulate-I: Carbon damages Granger cause COVID-19 and other factors while the reverse also holds for the stated variables. Thus, it confirmed the bidirectional relationship between them.

Postulate-II: There is a one-way linkage between the variables, i.e., carbon damages Granger cause COVID-19 cases and other factors, while the reverse does not hold for other causation. Thus, it confirmed the unidirectional relationship between them.

Postulate-III: The reverse causality exists in COVID-19 cases and carbon damages under different moderating and mediating factors, but the reverse does not hold. Thus, it confirmed the reverse causation between them, and

Postulate-IV: The stated variables do not Granger cause each other. Thus, it supports the neutrality hypothesis.

Finally, the study used variance decomposition analysis (VDA) under the VAR modelling framework under different lag operators. The forecast error decomposition allows to foresight the relationship between the stated variables over a time horizon. The greater magnitude of the variable on the main regression factor helps determine the frequency and size to predict the future change direction.

3. Results and discussion

Table 3 shows the descriptive statistics of the interested variables and found that carbon damages have a maximum value of 5.233% of GNI, a minimum value of 0.257%, and a mean value of 1.663%. The COVID-19 cases increase along with an increase in

Table 3. Descriptive statistics.

Methods	CARB_DAM	COVID19	GDP_PC	SQGDP_PC	FDI_INF	FDI_INF/ COVID19	GDP_PC/ COVID19	POP_DEN	POP_DEN/ COVID19
Mean	1.663	1595440	22389.09	9.52E + 08	3.039	1.62E - 05	0.122	242.790	2.04E + 08
Maximum	5.233	28381220	111062.3	1.23E + 10	28.346	0.00047	2.093	7952.998	4.98E + 09
Minimum	0.259	51047	1116.358	1246255	-16.061	-0.0003	0.00019	4.075	926428.9
Std. Dev.	1.213	4056142	21410.70	1.84E + 09	5.203	7.71E - 05	0.317	1016.700	6.65E + 08
Skewness	1.153	5.263	1.601	4.233	1.646	2.522	4.752	7.450	6.391
Kurtosis	3.574	33.586	6.171	25.630	14.784	26.778	27.441	57.009	45.893

Note: CARB_DAM shows carbon damages, COVID19 shows coronavirus cases, GDP_PC shows GDP per capita, SQGDP_PC shows a square of GDP per capita, FDI_INF shows inbound FDI, FDI_INF/COVID19 shows the share of FDI inflows in COVID19 cases, GDP_PC/COVID19 shows the share of GDP per capita in COVID19 cases, POP_DEN shows population density, and POP_DEN/COVID19 shows the share of population density in COVID-19 cases.

Source: Author's estimation.

Table 4. Markov switching regression (BFGS/Marquardt steps) estimates.

Dependent Variable: CARB_DAM				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
Regime 1				
CARB_DAM _{t-1}	0.356500	0.075069	4.748939	0.0000
COVID19	2.02E - 07	7.57E - 08	2.665884	0.0077
GDP_PC	-0.000133	1.75E - 05	-7.619423	0.0000
FDI_INF	0.021649	0.054147	0.399822	0.6893
POP_DEN	-0.010843	0.001183	-9.162716	0.0000
Constant	4.311054	0.348939	12.35475	0.0000
log(SIGMA)	-1.351943	0.246683	-5.480481	0.0000
Regime 2				
CARB_DAM _{t-1}	-0.093377	0.106891	-0.873578	0.3823
COVID19	-4.93E - 08	7.03E - 08	-0.701534	0.4830
GDP_PC	-7.59E - 05	1.71E - 05	-4.424314	0.0000
FDI_INF	-0.031878	0.040134	-0.794300	0.4270
POP_DEN	-0.000558	0.000240	-2.322904	0.0202
Constant	2.339277	0.391072	5.981706	0.0000
log(SIGMA)	-0.543267	0.155919	-3.484303	0.0005
Common				
SQGDP_PC	1.10E-09	2.99E-10	3.683176	0.0002
GDP_PC/COVID19	-1.535242	0.880168	-1.744259	0.0811
FDI_INF/COVID19	11574.22	4143.012	2.793673	0.0052
POP_DEN × COVID19	3.98E - 10	1.96E - 10	2.033003	0.0421
Transition Matrix Parameters				
P11-C	-0.432129	0.730400	-0.591633	0.5541
P21-C	-1.095450	0.559236	-1.958834	0.0501
Mean dependent var	1.677084	S.D. dependent var		1.218994
S.E. of regression	3.411578	Sum squared resid		477.1936

Note: CARB_DAM shows carbon damages, COVID19 shows coronavirus cases, GDP_PC shows GDP per capita, SQGDP_PC shows a square of GDP per capita, FDI_INF shows inbound FDI, FDI_INF/COVID19 shows the share of FDI inflows in COVID19 cases, GDP_PC/COVID19 shows the share of GDP per capita in COVID19 cases, POP_DEN shows population density, and POP_DEN/COVID19 shows the share of population density in COVID-19 cases.

Source: Author's estimation.

continued economic growth with an average value of 1,595,440. In contrast, the average per capita income of the cross-sectional panel of 60 countries is reached at US\$22,389.09. The inbound FDI has a greater value of 28.346% of GDP while its mean value is 3.039%. The square of GDP per capita and its share in the COVID-19 pandemic was used for analyzing the pandemic Kuznets curve hypothesis that reached their average value of US\$9.52E + 08 and US\$0.122, respectively. The positive average value of FDI and population density's share in COVID-19 would help to determine the existence of the pandemic pollution haven hypothesis and pandemic-population-pollution emissions hypothesis, respectively.

Table 4 shows the Markov switching regression estimates and found that the COVID19 cases increase carbon damage in regime 1. At the same time, this result is powerless to explain the relationship in regime 2. The result implies that coronavirus cases' rebound effect would likely worsen than negatively affect the natural environment once life returns and lockdowns are lifted worldwide. There is a negative relationship between countries' per capita income and carbon damages, implying that countries spent an enormous amount of money improving air quality. At the same time, at later stages, once pandemic emerged, its negative impact on countries' income and output level, which exacerbate carbon damages. Thus, the U-shaped relationship exhibited between the two factors during a pandemic crisis. The pandemic

Kuznets curve (PKC) is evaluated by doubling the countries per capita income and the share of per capita income relative to the COVID-19 pandemic and found that continued per capita income damages carbon emissions. Simultaneously, the greater sum of money devoted to healthcare infrastructure and environmental resource conservation helps to decrease carbon damages. Thus, it substantiates the PKC hypothesis across countries. The impact of FDI inflows on carbon emissions is not statistically significant in both regimes. However, the share of inbound FDI to COVID19 cases increases carbon damages, supporting the 'pandemic pollution haven' hypothesis across countries. There is a negative relationship between population density and carbon damages, implying that sustainable cities and smart building constructions played an important role in decreasing carbon damage. On the other hand, coronavirus cases' moderation effect on population density leads to increased carbon damages. It needs to be contained in coronavirus cases and reduce carbon emissions through sustainable health care policies. The result confirmed the pandemic-population-pollution hypothesis across countries.

The study results confirmed the following hypotheses that were designed during the wake of the COVID-19 pandemic. First, the COVID-19 pandemic is not limited to damages healthcare infrastructure while negatively affecting the environmental sustainability agenda across countries. The result is quite interesting, as due to strict lockdown in many parts of the globe, economic activities were decreases that substantially decreased carbon emissions. In contrast, economic activities increase after the COVID-19 first wave, which amplifies the cost of carbon emissions across countries. Thus, the rebound effect of the COVID-19 pandemic on the environmental sustainability agenda is another threat for the countries to maintain global average temperature less than 1.5° C. Secondly, the study postulates that the relationship between per capita income and carbon damages will be hump-shaped. The result confirmed the non-linear relationship between the stated variables. The economic activities initially supported reducing carbon damages because of strict measures adopted by the government to contain coronavirus cases; however, after lifted the lockdown, the economic activities enormously increased, increasing carbon damages across countries. Third, the percentage share of FDI inflows relative to COVID1-19 cases exacerbated carbon damages to support the pandemic Kuznets curve, another deteriorating factor that needs to be controlled through stringent government regulations. Finally, the study found that population density increases coronavirus cases due to increased social bindings among the population, leading to healthcare damages and environmental damages to verify the pandemic-population-pollution hypothesis across countries. These results we believe would be helpful to proposed sound healthcare sustainable policies to contain coronavirus cases and carbon damages worldwide. Comunian et al. (2020) found a high correlation between coronavirus cases and particulate matter emissions that negatively affect the individual's health, damaging lung cells and cause inflammation, which probably increases the high susceptibility of the coronavirus cases globally. Silva et al. (2021) concluded that plastic pollution was found higher during the coronavirus pandemic, which leads to a deteriorating natural environment and causes many healthcare inflammations, not limited to respiratory and lung diseases. A greater need to make sustainable policies for environmental

protection and coronavirus cases to address plastic pollution worldwide. Wang and Wang (2020) suggested that countries should be well prepared for the rebound effect of the COVID-19 pandemic to improve energy efficiency, carbon reduction, and sustainable development, which reduces carbon damages and coronavirus cases accordingly. Mishra et al. (2020) found the negative impact of stock market efficiency during the pandemic crisis, which led to severe financial depression across the globe. Bacchetta et al. (2021) argued that the COVID-19 pandemic largely disrupted the global value chains, including goods trading, healthcare logistics supply, and inventory management, which led to the severe global recession.

Table 5 shows the VAR Granger causality estimates for ready reference. The results confirmed the bidirectional causality between per capita income and FDI's share in COVID19 and between the square of GDP per capita and FDI's share in COVID19. The result implies that per capita income is the crucial factor that increases inbound FDI to reduce coronavirus cases across countries. On the other hand, the study found the unidirectional causality running from i) carbon damages to FDI inflows, population density, and FDI's share in COVID19 cases, ii) COVID19 to FDI inflows and share of population density to COVID19 cases, iii) GDP per capita to COVID-19 cases and FDI inflows, iv) FDI inflows to GDP's share in COVID19, v) population density to countries per capita income, FDI inflows, and GDP's and FDI's share in COVID19, and vi) population density to COVID-19 cases. The result implies that COVID-19 cases increase healthcare financing that elevated inbound FDI across countries. Further, continued economic growth increases coronavirus cases and inbound FDI accordingly. Finally, population density increases GDP's and FDI's share in COVID-19 cases along with countries per capita income and inbound FDI, which determine the link between population density and spread of coronavirus cases across countries.

Table 6 shows the VDA estimates of carbon damages in a panel of selected countries. The results suggested that the share of FDI inflows in COVID19 cases will have a greater magnitude to effect carbon damages with a forecast variance of 24.759%, followed by a share of GDP per capita in COVID-19 cases, population density, FDI inflows, and per capita income with a variance of 9.060%, 5.536%, 4.449%, and 3.553%, respectively. The least influenced will be population-induced carbon damages because of sustainable healthcare reforms with a variance of 0.035% for the next months.

4. Discussion

4.1. Conceptual contribution

The study's results align with the 'healthcare signalling' hypothesis, which argued that the positive healthcare signals could be delivered to the community members by addressing socio-economic and environmental issues in the wake of the COVID-19 pandemic. The world faced severe financial depression due to an unprecedented increase in the national healthcare bills to combat coronavirus cases, which affected the green development projects. The study's results show that humans exacerbate the current pandemic through their actions. Polluting firms, population compactness and

Table 5. VAR Granger causality estimates.

Variables	\sum CARB_DAM	\sum COVID19	\sum GDP_PC	\sum FDI_INF	\sum POP_DEN	\sum SQGDP_PC	\sum GDP_PC/COVID19	\sum FDI_INF/COVID19	\sum POP_DEN \times COVID19
\sum CARB_DAM	-	₺	₺	16,049*	8,485**	₺	₺	9,543*	₺
\sum COVID19	₺	-	₺	5,018***	₺	₺	₺	₺	105,782*
\sum GDP_PC	₺	7,220**	-	5,056***	₺	₺	₺	4,824***	₺
\sum FDI_INF	₺	₺	₺	-	₺	₺	9,818*	₺	₺
\sum POP_DEN	₺	₺	12,533*	11,634*	-	40,784*	124,343*	13,518*	₺
\sum SQGDP_PC	5,151***	₺	₺	4,819***	₺	-	₺	5,232***	₺
\sum GDP_PC/COVID19	₺	9,754*	₺	₺	₺	₺	-	₺	₺
\sum FDI_INF/COVID19	₺	₺	6,405**	7,452**	₺	27,495*	79,156*	-	₺
\sum POP_DEN \times COVID19	₺	185,426*	₺	₺	₺	₺	₺	₺	-

Note: ₺ shows no causality, * , *8, and *** shows 1%, 5%, and 10% level of significance, respectively. CARB_DAM shows carbon damages, COVID19 shows coronavirus cases, GDP_PC shows GDP per capita, SQGDP_PC shows a square of GDP per capita, FDI_INF shows inbound FDI, FDI_INF/COVID19 shows the share of FDI inflows in COVID19 cases, GDP_PC/COVID19 shows the share of GDP per capita in COVID19 cases, POP_DEN shows population density, and POP_DEN/COVID19 shows the share of population density in COVID-19 cases.

Source: Author's estimation.

Table 6. VDA estimates of carbon damages.

Months	CARB_DAM	COVID19	GDP_PC	GDP_PC/COVID19	FDI_INF	FDI_INF/COVID19	POP_DEN	POP_DEN × COVID19
September 2021	100	0	0	0	0	0	0	0
October 2021	92.839	0.083	2.515	0.019	0.357	0.548	0.526	0.051
November 2021	67.453	0.068	4.070	0.234	0.313	6.024	0.385	0.078
December 2021	52.065	1.032	5.823	0.302	1.822	6.536	8.173	0.068
January 2022	45.805	1.085	6.075	0.984	1.715	7.911	9.482	0.059
February 2022	34.325	0.865	7.128	8.923	3.235	14.569	7.837	0.043
March 2022	34.547	0.776	6.555	12.544	3.143	13.233	7.168	0.053
April 2022	24.151	0.546	4.589	10.139	3.825	21.761	6.644	0.042
May 2022	19.533	1.220	4.776	8.433	3.141	20.899	7.569	0.035
June 2022	13.586	1.141	3.553	9.060	4.449	24.759	5.536	0.035

Note: CARB_DAM shows carbon damages, COVID19 shows coronavirus cases, GDP_PC shows GDP per capita, SQGDP_PC shows a square of GDP per capita, FDI_INF shows inbound FDI, FDI_INF/COVID19 shows the share of FDI inflows in COVID19 cases, GDP_PC/COVID19 shows the share of GDP per capita in COVID19 cases, POP_DEN shows population density, and POP_DEN/COVID19 shows the share of population density in COVID-19 cases.

Source: Author's estimation.

irresponsible production and consumption, need to be tackled through stringent environmental regulations; information signals can undertake social distancing, and cleaner technology transfers can take on sustainable production and consumption. The following standpoints would improve positive healthcare signals, i.e.,

- i. To improve environmental standards through efficiency and safety standards, which help to reduce global healthcare losses.
- ii. Adopting the polluter-pays principle for conserving environmental resources.
- iii. Concentrated pollutants should be carefully monitored and compliance accordingly.
- iv. Adopt 'debt-for-nature swap' strategy for improving air quality standards, which is helpful to improve healthcare sustainability agenda, and
- v. Imposed pollution taxes for controlling carbon damages.

4.2. Practical implications

The world is severely affected by the Delta variant type of coronavirus disease, which is more lethal and concentrated into the air quickly. The increased rate of infected and death cases is reported globally, which is the only hope to get the vaccine on an equality basis to minimize healthcare sufferings. The following practical considerations should need to be adopted to avoid contact with the latest variant of coronavirus disease, i.e.,

- i. To avoid direct contact with the massive gatherings.
- ii. To get coronavirus vaccine and vaccinated to their close family members.
- iii. To adopt all safety measures as suggested by the governments and WHO from time to time.
- iv. Improve health hygiene and take care of their environment by avoiding fuel combustions and carbon pollutants.
- v. Use of eco-friendly goods and improve healthy living, and
- vi. Willing-to-pay for environmental protection and healthcare sustainability for avoiding dirty production.

The government should refocus its economic and environmental policies to ensure eco-supported strategies to improve environmental quality and achieve healthcare sustainability worldwide.

5. Conclusions

The study's objective is to evaluate different environmental hypotheses in the wave of the COVID-19 pandemic that negatively affects the inbound FDI and countries' economic output. The rebound impact of the COVID-19 pandemic would likely increase the cost of carbon emissions, while continued economic growth and population density influenced by the COVID-19 pandemic exacerbate carbon damages across countries. The study confirmed the pandemic Kuznets curve, pandemic pollution haven hypothesis, and pandemic-population-pollution hypothesis in the cross-sectional panel of 60 countries. The results confirmed the different cause-effect relationships between the stated variables, confirming the inter-temporal forecasting formwork that helped propose sound policy inferences globally.

- General policies

Based on the study's results, the following general and specific policies are suggested that followed to achieve healthcare sustainability agenda across countries, i.e.,

- i. *rebound effect of COVID-19 pandemic on environmental degradation*: The global world has taken many necessary measures to control coronavirus cases, indirectly impacting air quality indicators to achieve environmental sustainability agenda. Although the steps taken to control coronavirus cases cannot be prolonged due to decreasing economic output and efficiency, once the lockdown situation is lifted and economic activities begin to resume, the cost of carbon emissions is likely to increase at a tremendous rate. Hence, the rebound effect of the COVID-19 pandemic needs to be assessed, and policies should be drawn to keep control of carbon emissions for moving towards green growth agenda globally.
- ii. *adopting green financing projects in the wave of COVID-19 pandemic*: Financial development was severely disrupted during the pandemic, leading the global economies into a financial depression. Further, it increases the costs of carbon emissions that need to be controlled through advancement in cleaner production technologies and investment in the healthcare sustainability agenda that help control financial and healthcare pandemics accordingly.
- iii. *intelligent cities planning to avoid population compactness*: The increased population density causes social interaction that quickly transmits contagious diseases among the masses. Hence, it is necessary to adopt smart city planning and infrastructure development, which reduces infectious diseases and allows the populations to participate in environmental protection.
- iv. *Specific policies*

The more specific policies related to the study's findings are proposed accordingly, i.e.,

- The study's results show that the impact of the COVID-19 pandemic on carbon damages is positive, which confirms the adversity of contagious disease for environmental sustainability. The stringent policies measures to control coronavirus cases initially supported low carbon pollution because of strict/partial lockdowns in the cities and travel and transportation restrictions; however, it damages the natural environment when coronavirus cases substantially decline and resuming economic activities. Further, in the wake of the coronavirus pandemic, sustainable environmental measures were stopped, and the world is trying to minimize coronavirus cases, which obstructs the green developmental agenda. There is a time to refocus on sustainable environmental policies by innovative cleaner technologies and command-and-control mechanisms to move towards a healthy and clean developmental agenda.
- The U-shaped relationship between per capita income and carbon damages in the wake of the COVID-19 pandemic shows some leakages in the existing economic policies that cannot control carbon damages, leading to adversely affected healthcare sustainability agenda. The governments need to pay attention to economic production and healthcare supply chain to minimize carbon damages by incentive-based regulations, including the polluters-pay principle, carbon offset policies, and sustainable fuels used in logistics operations, and
- The pollution haven hypothesis is verified during the COVID-19 pandemic, as dirty production damages economic production and environmental sustainability agenda, adversely affecting the health infrastructure across countries. The Pareto-efficient outcome can be achieved by restricting polluting firms through stringent environmental regulations, including, imposition of carbon taxes and emissions-cap trading instruments to revitalize sustainable economic development.

The limitation of the study provides a basis for future directions research. The study can be improved by extending it to some specific world's regions and for individual countries to assess the efforts to control coronavirus cases at country-wide and region-wise analysis. Further, more variables can be added in a given model to obtain more generalized insights about the relationships between the variables including, supply chain factors, healthcare expenditures, coronavirus tests, coronavirus vaccines, and greenfield investment. These vital critical considerations need to be implemented to ensure green and clean economic development that helps it avoid any contagious diseases across countries.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The data is freely available at Worldometer (2021) at <https://www.worldometers.info/coronavirus> and World Development Indicators published by World Bank (2021) at <https://databank.worldbank.org/source/world-development-indicators>

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