

# An Investigation into the Nexus Between Human Development and Carbon Dioxide Emissions: A Global Panel Analysis

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## Abstract

A fact is that the environment remains an open-ended topic of paramount importance and interest in the literature. This is also true among decision-makers and the average person on “Main Street.” Another fact is that the momentum of human development is ongoing in most parts of the globe with higher wealth creation capabilities, better education and access to it, and better healthcare, all of which translate into a higher life expectancy. In that global context, it becomes a worthwhile endeavor to empirically assess the relationship between human development and pollution in the form of carbon dioxide emissions. Towards this end, the study considers different statistical and econometric methods involving granger-causality, panel vector error correction, and impulse responses. Using a broad panel of 139 countries sourced from the World Bank Group and United Nations Development Programme (UNDP) over the 1995–2018 period, results indicate some key takeaways and a material policy implication. Improvements in human development exacerbate pollution in the short run. However, in the long run, pollution is contained, even lessened, with improvements in human development. This latter outcome could be due to a growing class of environmentally conscious economic agents and decision-makers over time as economies mature. Such results should not constitute grounds for the pursuit of unchecked and incautious policies. To the contrary, all stakeholders should redouble their efforts in either devising or scrupulously implementing greener policies.

**Keywords:** Human development; Pollution; Carbon dioxide; Granger-causality; Panel vector error correction.

## 1. Introduction

The environment is a topic that draws interest, whether directly or indirectly, from people of all creeds, races and living conditions. With various degrees, this interest can morph into passionate debates, as it can be a matter of life or death in some parts of the world, especially in islandic or coastal areas. Case in point, the environment provides food and shelter, not only for humans, but for animals as well. It gives and supports life for all seven billion plus people living on the surface of the globe. Day in and day out, a vast footprint of polluting elements such as methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), ozone (O<sub>3</sub>), and carbon dioxide (CO<sub>2</sub>), among others, are released by billions of people and millions of factories and businesses. Societies throughout history have strived and vied in ingenuity to propose ways and means to address pollution from solid or gaseous waste. Thus, the quest for a clean environment is ingrained into human societies and justifies the interest aforementioned. Whether human societies are succeeding in this quest is up for debate as humanity is entering the third decade in the 21st century.

Against this background, it makes sense to explore the existence or not of a relationship, across time and space, between human emissions of gaseous waste – in general, and carbon dioxide (CO<sub>2</sub>), in particular – and human development. The focus on CO<sub>2</sub> is driven by a practical motive, as it is the most well-known and readily available across databases. Specifically, the primary research objective governing the current project is to determine the nature of causality between human development and carbon dioxide, and empirically assess it across countries and time.

At this juncture, an imperative question comes to mind in the following form: What is human development? In the 1970s, Dr. Mahbub ul Haq, an economist at the World Bank, introduced this notion into the public sphere and economic literature. It is defined as the process of expanding people’s freedoms and opportunities and improving their well-being. This definition filled a void in the literature, academia, and the arena of decision-makers and practitioners, in the sense that it goes beyond the usual metric of income. Indeed, the concept encompasses two other major social metrics, namely, health and education, in order to provide a more accurate assessment of well-being in a given society. The first Human Development Report, including the first human development index, was released in 1990. It was the outcome of a body of work commissioned by the United Nations Development Programme (UNDP)

through a group of prominent economists comprised of Dr. Haq and the 1998 Nobel Prize laureate in Economics, Amartya Sen, among others.

Overall, the paper is structured around five axes. The second axis is concerned with a review of literature. It is followed by a presentation of the methodological approach in the third. Results and implications are discussed with the fourth axis, while the study wraps up in the fifth part with the conclusion.

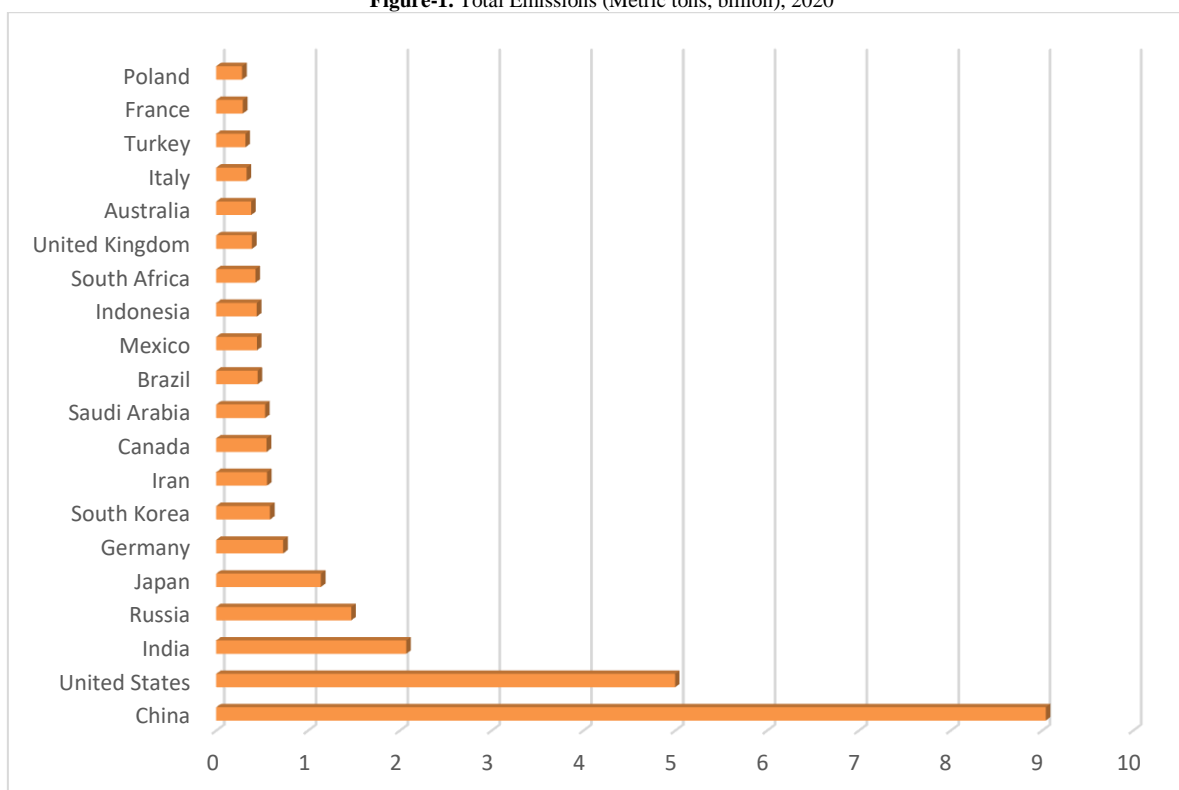
## 2. Literature Review

The literature is replete with research works and stylized facts pertaining to the environment and human greenhouse gases emissions, on the one hand, and human development, on the other. As far as the former is concerned, global emissions of CO<sub>2</sub> in particular rose from 33.1 gigatons to 36.2 gigatons between 2010 and 2017, according to *World Population Review* [1], which is a renowned source of data regarding populations and human activities across all continents. Furthermore, there was a yearly increase in the world average from around 4 tons per capita to 4.9 over this time period. Figures 1 and 2 provide a 2020 cross-section projection of key countries' total and per capita CO<sub>2</sub> footprints, respectively.

Regarding the latter, the United Nations Development Programme (UNDP) released in 2018 a report with human development indicators capturing the state of human development on every continent in the world. According to this report, two main takeaways can be highlighted. First, some progresses have been noted across the globe, but they have not been steady. Second, OECD (Organization for Economic Cooperation and Development) countries have shown the most promising results, whereas developing countries in South Asia and Sub-Saharan Africa have been lagging. It's noteworthy in passing that the OECD is a premiere and "global forum and knowledge hub focused on designing better policies to improve lives" in the world. As of 2021, it boasts a global membership of 38 countries<sup>1</sup>

Concerns about the state of earth's environment, including the preservation of its diverse ecosystems, have never been as heightened in this century as before. In their sweeping and insightful book, *Mavropoulos and Nilsen* [2] sound the alarm by stressing that humankind can no longer do business as usual. As urbanization accelerates across the globe, especially in developing countries, demand for food and food processing, resource extraction, and energy consumption, among others, will lead to an unsustainable level of pollution if humans do not operate differently. That is why they argue that the circular economy buoyed by the fourth industrial revolution is the only way forward for humanity. They define the circular economy as "an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes" (p. XXXIII).

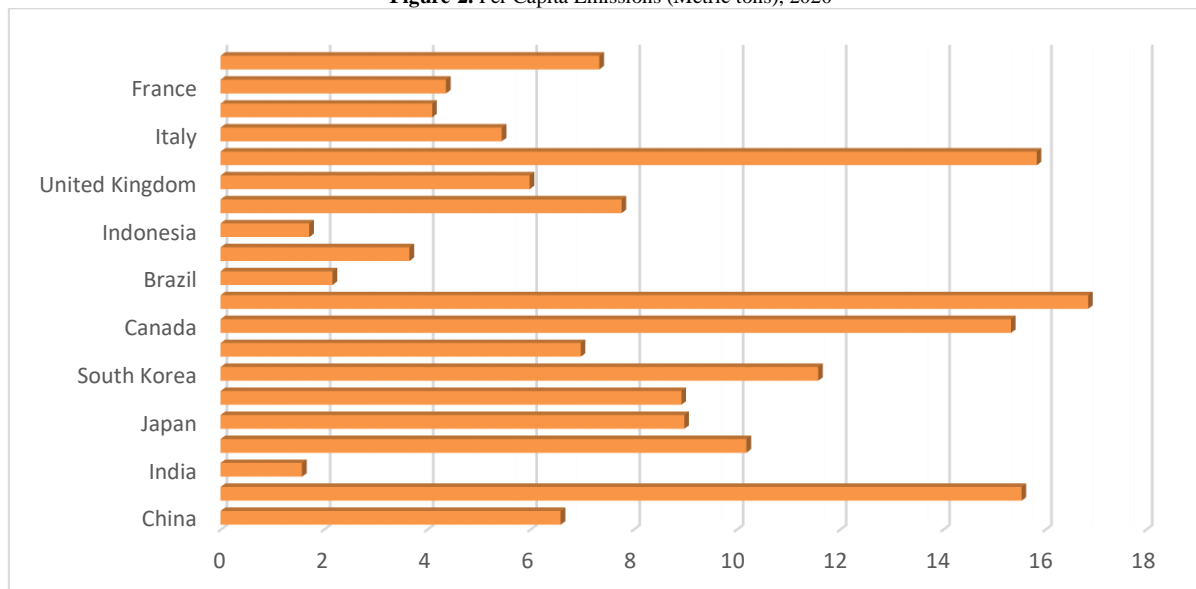
Figure-1. Total Emissions (Metric tons, billion), 2020



Source: World Population Review.

<sup>1</sup> Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States.

Figure-2. Per Capita Emissions (Metric tons), 2020



Source: World Population Review.

In a parallel stream of thoughts, Schröder and Storm [3] investigate whether de-carbonization to maintain future global warming at 1.5 °C is not beyond the realm of possibilities. They contend however that this will only materialize if human societies can dissociate economic growth from carbon emissions. Using both a prognosis of climate-constrained global growth for 2014–2050 within a transparent Kaya identity framework, and a Carbon-Kuznets-Curve paradigm, they uncover two main empirical facts. First, the decoupling of economic growth and carbon emissions is weak at best at high income levels. Second, they found evidence that carbon emissions increase with economic growth for the main sample comprising a dataset of 58 countries spanning from 2007 to 2015.

Environmental issues have been explored a great deal in the literature from a variety of angles. It is common knowledge that the original neoclassical growth model did not directly include discussions regarding the environment. Halkos and Psarianos [4] have intuitively proposed an augmented neoclassical growth model that accounts for the environment. This is done through a pollution and abatement mechanism, which considers the existence of renewable energy in the economy. Using a balanced panel of 43 OECD and non-OECD countries from 1990 to 2011, results are robust to validate the model both in static and dynamic specifications. Globally, they establish that the variables of the model capturing the environment – CO<sub>2</sub> emissions per capita and electricity production capturing pollution and the abatement mechanism, respectively – as well as GDP per capita – accounting for economic growth – are significant. In particular, they have found that the use of renewable energy is negatively related to CO<sub>2</sub> emissions.

Environmental awareness is essential in any context of human development and ultimately its improvement. In that regard, Xu, *et al.* [5] assess the impact of marine environmental awareness on economic development in coastal areas. Their work considers four different aspects of marine environmental awareness. They determine that such an awareness affects both the quality of marine environment and economic development in coastal regions.

Oftentimes, the effects of the environment go beyond the typical economy by reaching into and shaping social factors. In an attempt to shed light on the nexus between economic, social and environmental indicators, Babu and Datta [6] propose a study. The authors contend that it is critical to look at these three factors together to have an “integrated” and comprehensive understanding of an economy. In that perspective, they construct a model that endogenously considers indicators capturing the factors aforementioned through simultaneous equations. Using a dataset of 22 developing countries from Asia, Latin America and Sub-Saharan Africa over the 1980-2008 period, they come up with a key result. In essence, they empirically establish that bi-directional relationships do exist between developmental, social, and environmental indicators – such as GDP per capita, Environmental Degradation Index, life expectancy, literacy rate, labor force participation rate, fertilizers/herbicides/insecticides used per unit area, ores and metal exports, CO<sub>2</sub> emissions per capita, organic water pollution, population density, deforestation and gross enrollment. This finding corroborates the notion that environmental factors have far-reaching impacts.

Another notable perspective in the debate about the environment is the exploration of its relationship with international trade. In the footsteps of Pantelaiou, *et al.* [7], can we contemplate whether cleaner environment promote international trade? Using an international duopoly model, they provide a couple of answers to this question depending on the pollution abatement regime chosen. On the one hand, public pollution abatement regimes prove more potent in promoting exports. On the other hand, some revenue-recycling policies appear to be less important. That is for instance the case of policies wherein emission taxes levied upon polluting firms are returned to them.

Moreover, as far as international trade is concerned, Awad [8] focuses on 46 African countries from 1990 to 2017 and investigates the relationship between economic integration and the environment. The author empirically establishes through both parametric and non-parametric OLS techniques that intra-African trade promotes continent-wide environmental quality. Evidence supporting as well the environmental Kuznets curve (EKC) hypothesis is found. In other words, environmental quality eventually meliorates as income per capita or the economy grows.

A comparable reflection can be explored regarding the relationship between pollution and urbanization. It is a fact that the latter has mushroomed in recent decades across the globe. Borck and Pflüger [9] address this matter by asking if urbanization is good for the environment. Using a simple core-periphery model with monocentric cities, they realize that an urban system with cities of balanced sizes was more environmentally-friendly as it comes with less greenhouse gas (GHG) emissions. On the contrary, an urban system based upon a strong-core periphery asymmetry exhibits a larger carbon footprint.

### 3. Methodology

Three reputable methodological tools in the literature are considered: Granger causality, panel vector error correction (PVEC) and impulse-response functions (IRFs). A survey of the main features of these techniques is in order to help understand the empirical work in this investigation.

First, the direction of causality between human development and pollution is examined. As a matter of fact, correlation does not necessarily infer causation. Following in the footsteps of Granger [10], and using a balanced panel data of 139 country, let's define the following:

$$h_t = \delta + \sum_{p=1}^P \theta_p h_{t-p} + \sum_{p=1}^P \mu_p c_{t-p} + \varepsilon_t \quad (1),$$

Where  $h$  captures the human development index, while  $c$  accounts for pollution.  $p$  and  $t$  represent the lag and time subscript, respectively.  $\delta$  is the intercept, while  $\theta$  and  $\mu$  are lag-dependent coefficients.  $\varepsilon$  is the error term.<sup>2</sup>

For a panel of data, an explicit form of equation (1) is as follows:

$$h_{it} = \delta_i + \sum_{p=1}^P \theta_{ip} h_{it-p} + \sum_{p=1}^P \mu_{ip} c_{it-p} + \varepsilon_{it} \quad (2),$$

Where  $i$  represents a given country for all  $i = 1, 2, \dots, N$ , with  $N$  being the total number of countries in the panel.<sup>3</sup>

Two approaches are used to detect causality. On the one hand, it is assumed that all coefficients are the same across all cross-sections:

$$\theta_{i1} = \theta_{j1}, \theta_{i2} = \theta_{j2}, \dots, \theta_{iP} = \theta_{jP} \quad (3), \text{ for any pair of countries } i \text{ and } j.$$

$$\mu_{i1} = \mu_{j1}, \mu_{i2} = \mu_{j2}, \dots, \mu_{iP} = \mu_{jP} \quad (4), \text{ for any pair of countries } i \text{ and } j.$$

On the other hand, as proposed by Dumitrescu and Hurlin [11], it is assumed that all coefficients are different across all cross-sections:

$$\theta_{i1} \neq \theta_{j1}, \theta_{i2} \neq \theta_{j2}, \dots, \theta_{iP} \neq \theta_{jP} \quad (5), \text{ for any pair of countries } i \text{ and } j$$

$$\mu_{i1} \neq \mu_{j1}, \mu_{i2} \neq \mu_{j2}, \dots, \mu_{iP} \neq \mu_{jP} \quad (6), \text{ for any pair of countries } i \text{ and } j.$$

The authors show that the standardized average of Wald statistics for each cross-section follows a standard normal distribution.

Second, an impulse-response function (IRF) of the vector auto-regression model (VAR) is determined to assess the sensitivity of the dependent variable.

$$Y_t = \Gamma_1 Y_{t-1} + \Gamma_2 Y_{t-2} + \Gamma_3 Y_{t-3} + \dots + \Gamma_k Y_{t-k} + \Phi_t \quad (7)$$

$Y$  is a  $4 \times 1$  vector of macro-variables representing human development, pollution, economic activities, and population.  $\Gamma$  is a  $4 \times 4$  vector of coefficients, whereas  $\Phi$  is a  $4 \times 1$  vector of error terms.

### 4. Data, Results and Policy Implication

To complete the empirical segment of this study, a panel data comprising 139 countries from across the globe and spanning the period 1995-2018 is used. Data are derived from the World Development Index (WDI), published by the World Bank Group, and the United Nations Development Programme (UNDP)'s Human Development Report. Four key variables are selected: carbon dioxide emission ( $CO_2$ ), human development index (HDI), real output (RGDP) and population (POP). For informational purposes, Table 1 sums up some key descriptive statistics for each variable considered in the study.

Table-1. Descriptive statistics

	CO <sub>2</sub>	HDI	POP	RGDP
<b>Mean</b>	187651.274	0.67917386	43885708	4.2731E+11
<b>Median</b>	15540.746	0.7	9859790.5	3.8243E+10
<b>Maximum</b>	10291926.9	0.954	1.393E+09	1.7856E+13
<b>Minimum</b>	0.64874966	0.228	69650	291289880
<b>Std. Dev.</b>	778068.301	0.16576554	151722941	1.4581E+12
<b>Observations</b>	3336	3336	3336	3336

Tables 2 and 3 exhibit findings for cross-sectionally independent panel unit root tests. When common unit root processes are assumed, all variables are  $I(1)$  excepting POP, which comes out as  $I(2)$ . On the other hand, when individual unit root processes are in order, all but POP are  $I(1)$ . In this instance, POP essentially turns out as  $I(0)$ .

It is well-known that the outcomes of causality tests are highly sensitive to the choice of lag length, which is therefore critical. For completeness' sake, different specifications of causality tests, with both common and

<sup>2</sup> To find the existence of causality, an F-test is conducted. With the econometrics package EViews, the reported F-statistics are the Wald statistics for the joint hypothesis.

<sup>3</sup> This protocol investigates whether pollution granger-causes human development. A similar check is performed with the reverse causation. See Appendix for details about the protocol.

individual coefficients, are run and reported in tables 4 and 5, respectively. This is an attempt to verify whether there exists some empirical conclusiveness in the direction of causality. As far as causality tests with common coefficients are concerned, pairwise granger causality test results signal some divergence at lags 1 and 2 in the direction. Case in point, at conventionally accepted significance levels,<sup>4</sup> HDI granger causes CO<sub>2</sub>, while the latter does not. At lag 2, CO<sub>2</sub> granger causes HDI, while the latter does not. At lags 3 and 4, there is no empirical evidence of causality between HDI and CO<sub>2</sub>. When causality tests with individual coefficients are considered, it is found that HDI and CO<sub>2</sub> are mutually and homogeneously causing one another. That is, bidirectional causality is established.

At this juncture, the preliminary results of causality illustrate a lack of conclusive findings regarding its direction. It provides the basis to further explore the nexus between the two variables using a more comprehensive approach that uses VAR and cointegration techniques. The VAR is a highly pertinent estimation technique in this case considering that it equally and endogenously treats each variable in the system. In addition to HDI and CO<sub>2</sub>, two critical macro-variables are introduced, namely, RGDP and POP. The former is accounting for the extent of economic activities across time and societies, whereas the latter is controlling for the scale effect caused by sheer population differences.

**Table-2.** Unit root tests (H<sub>0</sub>: Unit root, with common unit root process)

	Statistic	Probability	Cross-sections	Observations
CO <sub>2</sub>				
<b>Levin, Lin &amp; Chu t</b>	6.4021	1	139	3104
<b>Breitung t-stat</b>	10.0742	1	139	2965
D(CO <sub>2</sub> )				
<b>Levin, Lin &amp; Chu t</b>	-21.9924	0	139	2977
<b>Breitung t-stat</b>	-11.7676	0	139	2838
HDI				
<b>Levin, Lin &amp; Chu t</b>	-3.00029	0.0013	139	3096
<b>Breitung t-stat</b>	5.96014	1	139	2957
D(HDI)				
<b>Levin, Lin &amp; Chu t</b>	-25.1387	0	139	3010
<b>Breitung t-stat</b>	-15.1954	0	139	2871
POP				
<b>Levin, Lin &amp; Chu t</b>	0.95898	0.8312	139	2825
<b>Breitung t-stat</b>	3.59879	0.9998	139	2686
D(POP)				
<b>Levin, Lin &amp; Chu t</b>	1.7806	0.9625	139	2752
<b>Breitung t-stat</b>	8.03908	1	139	2613
D(D(POP))				
<b>Levin, Lin &amp; Chu t</b>	-34.9876	0	139	2780
<b>Breitung t-stat</b>	-5.43347	0	139	2641
RGDP				
<b>Levin, Lin &amp; Chu t</b>	1.23396	0.8914	139	3085
<b>Breitung t-stat</b>	11.6822	1	139	2946
D(RGDP)				
<b>Levin, Lin &amp; Chu t</b>	-22.5011	0	139	2998
<b>Breitung t-stat</b>	-7.83911	0	139	2859

**Table-3.** Unit root tests (H<sub>0</sub>: Unit root, with individual unit root process)

	Statistic	Probability	Cross-sections	Observations
CO <sub>2</sub>				
<b>Im, Pesaran and Shin W-stat</b>	4.55456	1	139	3104
<b>ADF - Fisher Chi-square</b>	305.602	0.1226	139	3104
<b>PP - Fisher Chi-square</b>	257.311	0.8083	139	3197
D(CO <sub>2</sub> )				
<b>Im, Pesaran and Shin W-stat</b>	-31.7349	0	139	2977
<b>ADF - Fisher Chi-square</b>	1474.14	0	139	2977
<b>PP - Fisher Chi-square</b>	2845.68	0	139	3058
HDI				
<b>Im, Pesaran and Shin W-stat</b>	1.24529	0.8935	139	3096
<b>ADF - Fisher Chi-square</b>	292.409	0.2647	139	3096
<b>PP - Fisher Chi-square</b>	214.708	0.9981	139	3197
D(HDI)				
<b>Im, Pesaran and Shin W-stat</b>	-24.4866	0	139	3010

<sup>4</sup> 10% or less.



<b>ADF - Fisher Chi-square</b>	1099.29	0	139	3010
<b>PP - Fisher Chi-square</b>	1431.5	0	139	3058
POP				
<b>Im, Pesaran and Shin W-stat</b>	-3.50107	0.0002	139	2825
<b>ADF - Fisher Chi-square</b>	640.17	0	139	2825
<b>PP - Fisher Chi-square</b>	227.996	0.9873	139	3197
D(POP)				
<b>Im, Pesaran and Shin W-stat</b>	-9.19044	0	139	2752
<b>ADF - Fisher Chi-square</b>	708.913	0	139	2752
<b>PP - Fisher Chi-square</b>	347.107	0.003	139	3058
RGDP				
<b>Im, Pesaran and Shin W-stat</b>	6.98222	1	139	3085
<b>ADF - Fisher Chi-square</b>	228.478	0.9865	139	3085
<b>PP - Fisher Chi-square</b>	143.186	1	139	3197
D(RGDP)				
<b>Im, Pesaran and Shin W-stat</b>	-19.1432	0	139	2998
<b>ADF - Fisher Chi-square</b>	887.748	0	139	2998
<b>PP - Fisher Chi-square</b>	1239.73	0	139	3058

Panel cointegration tests are conducted using the Johansen Fisher method with 1, 2 and 3 lag intervals for first differenced variables. Table 6 confirms the existence of multiple cointegration equations (CEs) among the four variables. Thus, panel cointegration estimations are determined and outlined in Table 7. Improvements in human development across time and societies lessen pollution in general and CO<sub>2</sub> emissions in particular in the long run. Moreover, these impacts remain significant at the 5 percent level even with economic activities and populations under control. However, in the short run, improvements in human development worsen pollution with a stronger significance level of 1 percent.

Table-4. Causality tests (Common coefficients)

<b>Lags: 1</b>			
<b>Null Hypothesis:</b>	<b>Observations</b>	<b>F-Statistic</b>	<b>Prob.</b>
HDI does not Granger Cause CO <sub>2</sub>	3197	15.2061	0.0001
CO <sub>2</sub> does not Granger Cause HDI		2.00287	0.1571
<b>Lags: 2</b>			
<b>Null Hypothesis:</b>	<b>Observations</b>	<b>F-Statistic</b>	<b>Probability</b>
HDI does not Granger Cause CO <sub>2</sub>	3058	1.8531	0.1569
CO <sub>2</sub> does not Granger Cause HDI		2.32608	0.0979
<b>Lags: 3</b>			
<b>Null Hypothesis:</b>	<b>Observations</b>	<b>F-Statistic</b>	<b>Probability</b>
HDI does not Granger Cause CO <sub>2</sub>	2919	0.28968	0.8329
CO <sub>2</sub> does not Granger Cause HDI		1.39705	0.2418
<b>Lags: 4</b>			
<b>Null Hypothesis:</b>	<b>Observations</b>	<b>F-Statistic</b>	<b>Probability</b>
HDI does not Granger Cause CO <sub>2</sub>	2780	0.23524	0.9186
CO <sub>2</sub> does not Granger Cause HDI		1.0064	0.4028

Table-5. Causality tests (Individual coefficients)

<b>Lags:1</b>			
<b>Null Hypothesis:</b>	<b>W-Statistic</b>	<b>Zbar-Statistic</b>	<b>Probability</b>
HDI does not homogeneously cause CO <sub>2</sub>	3.78409	18.4041	0
CO <sub>2</sub> does not homogeneously cause HDI	3.28209	14.9476	0.00E+00
<b>Lags:2</b>			
<b>Null Hypothesis:</b>	<b>W-Statistic</b>	<b>Zbar-Statistic</b>	<b>Probability</b>
HDI does not homogeneously cause CO <sub>2</sub>	4.67699	10.9633	0
CO <sub>2</sub> does not homogeneously cause HDI	3.38116	5.06924	4.00E-07
<b>Lags: 3</b>			
<b>Null Hypothesis:</b>	<b>W-Statistic</b>	<b>Zbar-Statistic</b>	<b>Probability</b>
HDI does not homogeneously cause CO <sub>2</sub>	5.98781	8.38025	0
CO <sub>2</sub> does not homogeneously cause HDI	4.99557	5.03787	5.00E-07
<b>Lags: 4</b>			
<b>Null Hypothesis:</b>	<b>W-Statistic</b>	<b>Zbar-Statistic</b>	<b>Probability</b>
HDI does not homogeneously cause CO <sub>2</sub>	8.56432	9.19809	0
CO <sub>2</sub> does not homogeneously cause HDI	6.32775	3.60089	0.0003

Some real-world rationales could lend support to such findings. Indeed, a growth of human development index in a given society, and by extension the world, reflects the presence of more educated people, with better healthcare or health, who live longer in addition to enjoying a higher standard of living. These facts in turn lead economic agents to be more environmentally-conscious through, for instance, recycling, recovering, and/or the pursuit and adoption of renewable energy sources. Businesses and factories strive to implement more efficient and less polluting technologies. We cannot overlook on the other hand the impacts and growing pressure exerted by social movements or groups as they push for and embrace greener policies. In many instances, these policies wind up being included in platforms of political parties and beyond. Decision-makers are encouraged, even compelled in some cases, to formulate – or at least try, in earnest – public policies with greener or more environmentally-friendly inputs. Furthermore, the speed of adjustment of HDI towards the long run equilibrium remains low at about 2.3% per annum.

Table-6. Panel cointegration tests<sup>5</sup>

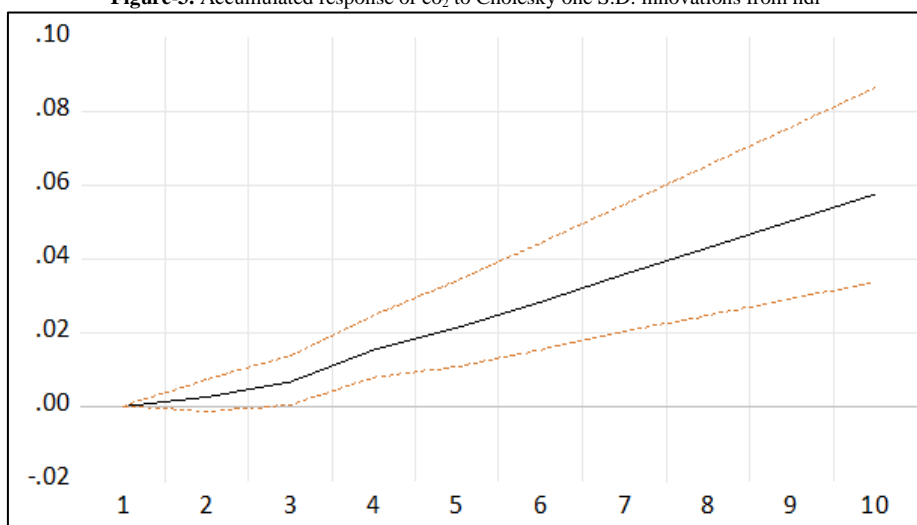
	Hypothesized No. of CE(s)	Trace Statistic	Probability	Max-eigenvalue	Probability
Lag(s): 1					
	None	4437	0	8420	0
	At most 1	1520	0	985.2	0
	At most 2	769.7	0	574.1	0
	At most 3	442	0	442	0
Lag(s): 2					
	None	6544	0	10769	0
	At most 1	3524	0	2191	0
	At most 2	1709	0	1195	0
	At most 3	791.9	0	791.9	0
Lag(s): 3					
	None	1134	0	4741	0
	At most 1	7934	0	5196	0
	At most 2	19207	0	3810	0
	At most 3	2277	0	2277	0

Table-7. Estimation results<sup>6</sup>

	hdi	rgdp	pop	c	F-statistic	Probability
Cointegration	-0.83112**	2.183966***	0.314404	-0.05225	205.0301	0
	d(hdi)	d(rgdp)	d(pop)	c		
Error correction	0.022777***	0.418166***	-0.00154	-0.00086		

Another important piece of information uncovered by findings can be observed through the impulse response function of pollution over a 10-year period. As a matter of fact, it appears that CO<sub>2</sub> emissions continuously rise following a Cholesky one standard deviation shock. However, the increase in these emissions barely peaks to 6 percent over decade (Figure 3).

Figure-3. Accumulated response of CO<sub>2</sub> to Cholesky one S.D. innovations from hdi<sup>7</sup>



<sup>5</sup> Probabilities are computed using asymptotic Chi-square distribution.

<sup>6</sup> Lowercase variables are in log form. \*, \*\*, and \*\*\* indicate significance at the 10, 5, and 1% level, respectively.

<sup>7</sup> The band represents a 95% C.I.

Empirical results highlight a major policy implication regarding the interplay between pollution, through CO<sub>2</sub> emissions, and human development. There is no incompatibility between pursuing, on the one hand, steady advancements in humankind's quality of life worldwide and containing or curtailing, on the other hand, pollution. The legitimate aspiration of every society for better standards of living for their respective populations can be achieved without incurring undue pollution costs. The caveat, however, is that the lack of incompatibility, which is propitious, should not be construed as a blank check to engage in careless policies in this quest for improved quality of life. It therefore behooves decision-makers to heed these implications to put society onto a balanced and resilient path towards prosperity for all, including both current and future generations.

## 5. Conclusion

The nexus between human development and carbon dioxide emissions is not straightforwardly clarified through a usual granger causality approach. A system of vector error corrections, with a sizeable panel data comprising 139 countries from all corners of the globe, has helped provide some useful insights regarding the dynamics of this interplay. In the short run, progress in human development is burdened by a rise in pollution. Yet, in the long run the reverse is noted as higher human development curbs pollution certainly due to the implementation of more informed policy choices and the pressure of more environmentally conscious constituencies or populations.

## Appendix

Similarly to eqs. (1) and (2), the protocol described below is used to investigate whether human development granger-causes pollution:

$$c_t = \delta' + \sum_{p=1}^P \theta'_p c_{t-p} + \sum_{p=1}^P \mu'_p h_{t-p} + \varepsilon'_t \quad (1')$$

$\theta'$  and  $\mu'$  are lag-dependent coefficients respectively associated with pollution and human development.

For a panel data, an explicit form of equation (1') is as follows:

$$c'_{it} = \delta'_i + \sum_{p=1}^P \theta'_{ip} c'_{it-p} + \sum_{p=1}^P \mu'_{ip} h'_{it-p} + \varepsilon'_{it} \quad (2')$$

where  $i$  represents a given country.

Similarly, two approaches are used to detect causality with the following series of tests:

1)

$$\theta'_{i1} = \theta'_{j1}, \theta'_{i2} = \theta'_{j2}, \dots, \theta'_{iP} = \theta'_{jP} \quad (3'), \text{ for any pair of countries } i \text{ and } j.$$

$$\mu'_{i1} = \mu'_{j1}, \mu'_{i2} = \mu'_{j2}, \dots, \mu'_{iP} = \mu'_{jP} \quad (4'), \text{ for any pair of countries } i \text{ and } j.$$

2)

$$\theta'_{i1} \neq \theta'_{j1}, \theta'_{i2} \neq \theta'_{j2}, \dots, \theta'_{iP} \neq \theta'_{jP} \quad (5'), \text{ for any pair of countries } i \text{ and } j$$

$$\mu'_{i1} \neq \mu'_{j1}, \mu'_{i2} \neq \mu'_{j2}, \dots, \mu'_{iP} \neq \mu'_{jP} \quad (6'), \text{ for any pair of countries } i \text{ and } j.$$

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