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Research Article

Fossil Fuel Consumption, CO_2 Emissions and Growth in High-Income Countries and Low-Income Countries

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ABSTRACT

This paper investigates the pairwise causality and co-integration that links fossil fuel consumption (FFC), carbon dioxide (CO_2) emissions, and real gross domestic product (RGDP) between low-income countries (LIC) and high-income countries (HIC). This comparative analysis is anchored on Lv et al. (2019). Lv et al. (2019) enable the analytical framework model utilized to investigate the causality between FFC and CO_2, CO_2 and RGDP, and FFC and RGDP in HIC and LIC. Data were obtained from world development indicator between 1960 and 2019. The results obtained are, as follows: There exists a unidirectional causality, thus the RGDP granger causes CO_2 in HIC, and no causality between RGDP and CO_2 in LIC. Also, the study found no causality between FFC and RGDP, and FFC and CO_2 in HIC and LIC. The mixed inter-regional causality result showed that there exists bi-directional causality between RGDP and CO_2 for HIC and LIC. This implies that RGDP in LIC granger causes CO_2 in HIC, and CO_2 in HIC granger causes RGDP in LIC. Hence, the presence of a regional super-wicked problem. Also, CO_2 in HIC granger causes FFC in LIC. The result suggests that countries should seamlessly adopt proportionate mitigation and adaptation policies to reduce the pollution transmission between economies. The non-existence of pairwise co-integration between FFC, CO_2, and RGDP in HIC and LIC connotes that the CO_2 reduction policy should be a short-term public policy strategy with conscious and deliberate targeting to avoid long-run growth reversal. Therefore, this paper concludes that reducing FFC may not necessarily lead to a decline in growth vice versa. Thus, to achieve a low carbon economy and a high growth regime, the global community should adopt a techno-economic paradigm model that would accelerate growth within a low-carbon economy regime to realize the 45% carbon reduction target by 2030 and the 2050 net-zero emission target.

Keywords: fossil fuel consumption (FFC), climate change, CO_2 emissions, real gross domestic product (RGDP), granger causality, regional super-wicked problem, high-income countries (HIC), low-income countries (LIC)

INTRODUCTION

The prevalence of the super-wicked problem is one of the biggest trepidation for environmental economists. However, there is an emerging puzzle connecting the regional impact of fossil fuel consumption (FFC) on regional carbon dioxide (CO_2) emission, regional CO_2 impact on regional growth, and regional growth impact on CO_2. Efforts to reconcile this emerging puzzle seem inconclusive in the literature. FFC (combustion) cause pollution that jerks-up greenhouse gases which in turn cause climate change problem. The chain reaction is that FFC causes CO_2 emissions, CO_2 emissions leads to climate variability, climate variability causes shock and risk to the global economy through the unprecedented weather (flooding) channel and financial loan risk channel. Patz et al. (2018) posit that the overall impact of environmental shock and climate change vulnerability in the trends of greenhouse gases can be viewed from the rising temperature, precipitation, sea level, and ocean acidification. In the long-run climate change vulnerability could cause severe trepidation for the global economy. Since there is a perceptible global atmospheric interdependence, regional climate change shock can impede regional growth vice versa. Most economies largely depend on fossil fuel for their economic survival in terms of production, consumption, distribution, and exchange that stimulate growth. The nexus between FFC, CO_2, and real gross domestic product (RGDP) threatens the existing growth model due to the absence of climate change issue. In order to achieve the global carbon emissions target in 2030, scholars are deeply apprehensive about the super-wicked problem surrounding climate change and growth nexus.

Furthermore, the super-wicked problems controversially affect the optimum policy-planning dimension in the climate change mitigation-adaptation legislation. Typically, a super-wicked problem creates a planning-policy scenario on the optimal platform that enables the achievement of high, rapid, and sustainable economic growth and low carbon emission simultaneously. Unfortunately, the existence of a trade-off between growth and climate change targets causes policy planning mix-up. At the center of policy-travesty there is the probable causal impact between the climate changes and growth vice versa have which could leave the fossil-fuel dependent economy in a worse-off position. Therefore, the puzzle becomes how best to enhance climate change control and regulation, attain re-balancing and restructuring of global FFC and energy mix, and the optimal input combination that can guarantee a green economy. As scholars contemplate the solutions to these puzzles, the literature acknowledges that time is running out and the contributors of climate change constitute policy healing blocks to ending climate change. What is the optimal trade-off between climate change and economic growth required to get mitigation policy right? How could a high carbon-emitting economy respond to the vulnerability of climate change matrix manifested through flooding, unpredictable weather patterns, and shocks on economic outlook? What is the causal impact that permeates climate change and growth nexus?

This paper addresses question of a causal relationship between climate change and growth. The significance of this study is anchored on the causal relationship between climate change and growth. The CO_2 in low-income countries (LIC) remains relatively low, the question becomes does high CO_2 in high-income countries (HIC) imply high CO_2 in LIC holding CO_2 in middle-income countries (MIC) constant? What is the causal linkage between fossil fuel and economic growth in LIC and HIC? and does causality exist between CO_2 and economic growth in LIC and HIC? The motivating question adduced in this paper becomes what is the causality between FFC and CO_2, FFC and RGDP, CO_2 and RGDP? Thus, this study aims to compare the causal relationship between FFC (or combustion), CO_2 emission, and RGDP (a proxy for economic growth) in LIC and HIC. This study proposed five fundamental hypotheses:

1. There is causality existing between FFC and CO_2;
2. There is causality existing between CO_2 and RGDP;
3. There is causality between FFC and RGDP;
4. There is regional causality between CO_2 and RGDP; and,
5. There is no long-run relationship between CO_2 and RGDP.

This paper is divided into five parts namely, introduction, literature review, methodology, discussion, and conclusion.

LITERATURE REVIEW

Before we delve into the discussion of the theoretical and empirical reviews. It is imperative to provide a brief emerging issues of climate change reversal (Skoufias, 2012). The prevailing issues in the FFC, CO_2, and RGDP debate affect the global optimal mitigation mix between HIC and LIC or between high emitting economies and low emitting economies. There is the nationally determined contributions (NDCs) target which requires a 45% reduction in global emissions by 2030 and net-zero emission target of 2050. When fossil fuel is anthropogenically utilized large amounts of CO_2 emissions are generated and released into the air. Greenhouse gases (GHG) traps heat in the environment, causing global warming. GHG emissions include CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), nitrogen trifluoride (NF_3), fluorinated ethers (HFEs), etc. They are gases that are generated within the thermal infrared range that adds to the GHG effect and global climate change. Evidence shows that the shift in the global average temperature (GAT) from the El Nino event to La Nino did not cause a corresponding downward shift in the GAT frontier. Nevertheless, the 2020 GAT is estimated to be at 1.2°C higher than the 1850-1900 pre-industrial baseline and comparable to the previous GAT's record of 2016 (WMO, 2020). Historically, conscious efforts to address remote and immediate causes of climate change are traceable to breakthrough of the Cancun Agreement of the United Nations Framework Convention on Climate Change (UNFCCC). UNFCCC Article 2 states that there shall be a "stabilization of GHG concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." Article 2 has been re-affirmed in the 1992 Rio Earth Summit, 1997 the Kyoto Protocol, and the 2015 Paris Agreement, etc. Specifically, the Paris Agreement is an international treaty on climate change adopted by 196 countries at Conference of Parties 21, in Paris. The goal of the Paris Agreement is to limit global warming to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels (IPCC, 2022; UNFCCC, 2021). According to UNFCCC (2021), Paris Agreement established an enhanced transparency framework (ETF). The ETF "improve statistic on the global stock take that assesses the collective progress towards the long-term climate goals. Also, the greenhouse gas protocol provides the foundation for sustainable climate strategies and more efficient, resilient, and profitable organizations" (IRSA, 2013). Climate change impact poses an uncertain risk to the global economy. The unpredictable nature of the ecosystem could result in a high loss of essential features that supports lives and health. Between 2030 and 2050, climate change could generate over 250,000 additional deaths. In the past 130 years, the world has warmed by a close value of 0.850°C. The level of CO_2 in the Earth's atmosphere has been rising consistently for decades and traps extra heat near the surface of the earth causing the temperature to rise (NASA, 2021). The unfathomable global environment shock emanating from disproportionate contributions of CO_2 emissions in LIC (CO_2LIC), MIC (CO_2MIC), and HIC (CO_2HIC) has become a burning and disturbing inevitable tragedy too threatening to neglect to chance (**Figure 1**).

However, FFC-CO_2 emissions, CO_2 emissions and economic growth, and economic growth-FFC relationships are supported by an empirical linkage in super-wicked problem hypothesis. Fossil fuel exploration causes an upward concentration shift in GHG concentration which creates unimaginable damage cost, in turn, causes environment shock (WMO, 2020). This environmental shock causes global warming (heat-trapping in the ecosystem) that creates climate vulnerability impact on environment by causing a substantial decline in agricultural

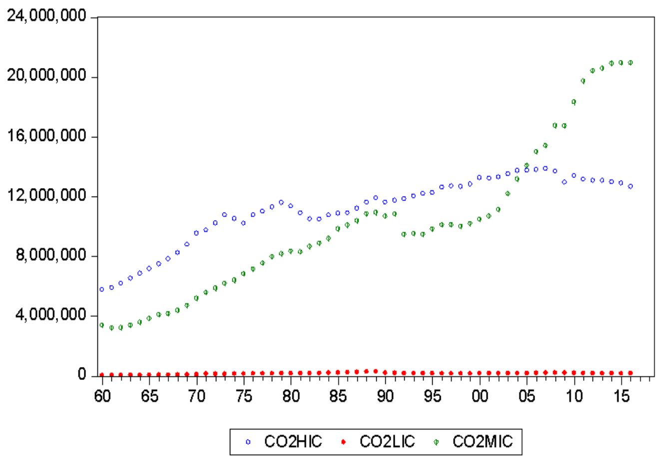

Figure 1. Global CO_2 emission (1960-2016)

productivity, thus making it increasingly difficult to achieve economic growth and sustainable development goals.

Theoretical Review: Complex Theory

Wicked problems revolve around the policy-planning relationship of the political class due to their involvement in leveraging machinery to solve the climate change issue (Sun and Yang, 2016). Climate change is a wicked problem borne out of the complexity in the effecting change that has multiple and conflicting inputs and multiple possible outcomes (Head, 2008; Incropera, 2015). Rittel and Webber (1973, p. 161-166) identified properties of wicked problems. They are, as follows: there is no definitive formulation, no ends to causal chains, no true-false solutions rather good-bad solutions, no immediate or ultimate test for a solution, every attempt at a solution is consequential, no exhaustive set of solutions, it is unique, every wicked problem points to other wicked problems, discrepancies have multivariate dimension-choice of solutions determines the nature of the problem's resolutions, wicked problems create an organization, stakeholder, fragmentation and institutional problems (Conklin, 2016; Whelton & Ballard, 2002). These complexities and uncertainty exist because of the dynamic properties of the system upon which wicked problems thrive.

The complex theory is built on the general system theory (Lazarus, 2009). Grobman (2005) maintains that environmental problem is complex because of the systems interrelatedness and interconnectedness of actions and reactions. Each system has a hierarchy and subsystem that establishes a pattern of dynamic interactions hence any perceptible reordering or alterations generates a domino effect (Simon, 1962), setting variants actions into motion in an opposite, unpredictable dimension with unpredictable consequences (Barabasi, 2003).

According to Peters (2017) and Peters et al. (2017), emerging climate-poverty mix is defined as complex, related to multiple possible causes and internal dynamics which have negative consequences for society if not addressed properly. Thus, the development of the complex theory is based on the existence of wicked problems. Complexity theory identified that a small shift around policy indicators could produce a massive difference in the outcome that is politically and technically complex (see also social mess theory). According to Rittel and Webber (1973), ten properties of wicked problems implicitly captured the complexity of consequential reactions of the policy change and direction of change with ultimate price of policy failure due to complexity- interconnectedness, and motives within the system. Aside from complex theory, path-dependence theory provides a glimpse of the impact of structural adjustment and the technical progress in terms of technology adoption. According to Unruh (2000), path-dependent analysis in the debate of super-wicked problem can be resolved by understanding how path-dependent policy is produced to affect future policy needs. This is owing to the fact that technology adoption creates high carbon hence a counterbalancing policy to create technology adoption with low carbon with path-dependency epistemology thinking (in Levin et al., 2012).

Empirical Review

Economists' interest in the super-wicked problem hypothesis can be decomposed into three components. This study robustly focused on one of the worries in the economics of climate change. The study is concerned with the transmission causality channels between climate change shock (proxy by CO_2 emission) and economic growth.

Cederborg and Snobohm (2016) observed a relationship between per capita gross domestic product (GDP) and per capita CO_2 emissions. The implication of the study connotes that an increasing GDP per capita results in a higher CO_2 emission. Kasperowicz (2015) studied the relationship between CO_2 emission and GDP for 18 EU countries from 1995 to 2012. The study found a negative long-run relationship between GDP and CO_2. Rozenberg and Hallegate (2015) found a link between climate change and poverty to be based on the nature of demographic and socio-economic trends. Hallegate et al. (2014) identified productivity, prices, assets, and opportunities as the major determinates that explain the causality between poverty and climate change. Leichenko and Silva (2014) demonstrated that climate change-poverty linkages are complex, multifaceted, and country-specific. The study identified direct channels (agricultural productivity) and immediate channels (flood and drought) cause climate change vulnerability that leads to inequality within the climate change-poverty trap cycle trajectories.

Gupta (2014) found the relationship between climate change, population, and economic growth. The study found that carbon emission per capita has declined in developed countries but worrisomely growing in developing countries due to population growth and economic growth. Economic growth and population growth contribute most to increasing emissions globally and have an out-paced improvement in energy efficiency.

A similar dimension, is the cost of implementing energy and industrial policies, especially fossil fuel industries, and deep structural changes in the global economic frontier. Hertel and Rosch (2010) captured the link between climate change-agriculture-poverty. The study found that direct linkage (payment for environmental services) and indirect linkage (factor market) exist between climate change mitigation and poverty. Reid and Swiderska (2008) developed a study that estimated the relationship between biodiversity, poverty, and climate change. Thornton et al. (2008) found that the

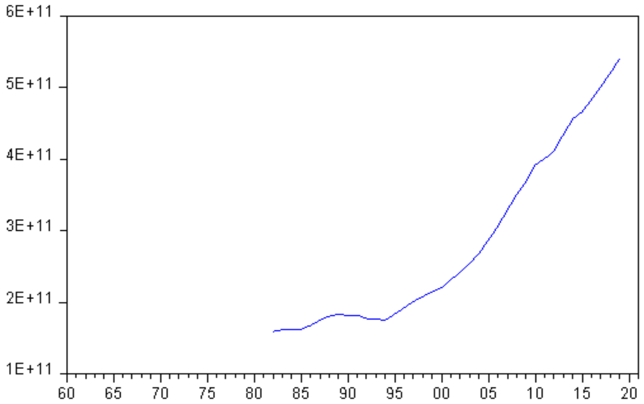

Figure 2. RGDP LIC/Time

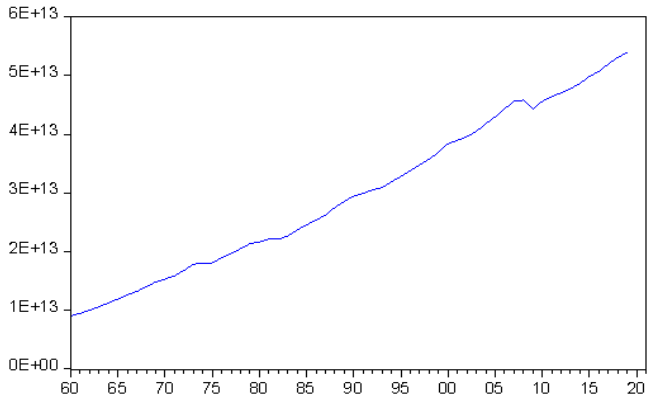

Figure 3. RGDP HIC/Time

explanatory variable that climate change vulnerability dictates the causality between poverty and climate change.

Review of Literature

The recent literature is silent on the FFC, CO_2, and growth causality for LIC and HIC in its comparative form. In this paper, our target is on environmental-growth causality which is one of the linkages in super-wicked problems as conceptualized by Lv et al. (2019). Most recently, there is a deeper shift in the environment-GDP literature to include how best to determine the optimal mitigation for the global economy that guarantees sustainable growth.

METHODOLOGY

This study adopts a quasi-experimental research design approach. The general analytical framework for this study is obtained from the study conducted by Hallegatte et al. (2014). As a point of departure, this paper captures the comparative causality between FFC, CO_2 emissions, and GDP per capita in LIC and HIC. Granger causality is utilized to examine the cause and effect that exist between two theoretical nexuses. The test enables us to identify whether changes in one variable X affect the change in variable Y. The method is employed to investigate the extent to which feedback effect or two-way (bi-directional or unidirectional) impact can be ascertained from an economic relationship. The granger causality test is built around the probability definition of whether one-time series is empirically significant for forecasting another. The idea behind this method is to align this paper with the existing debate that supper-wicked problems exist in the climate change and growth targets. The granger causality result would enable policymakers to make policy actions that can stimulate growth and reduce carbon emission in both regions simultaneously. This study considers HIC and LIC as a single country in the climate action plan. This assumption became necessary because of the existing debate that HIC is a major pollution contributor and LIC is less contributor to pollution that aggravates GHG emissions.

Model

The apriori expectation conditioning the causality between economic growth and CO_2 emissions is mixed. However, environmental kuznets curve (EKC) provides a nexus on the increasing functional linkage between environmental damage and per capita income at the beginning of economic growth and declines afterward. The rising CO_2 concentration in the ecosystem and the mitigation issues provide adequate background between CO_2 emissions and economic growth. Thus, the super-wicked problem exists because of the foregoing underpinning causality between reduction of the CO_2 shock and benefit on the environmental sustainability. Thus, this paper follows Lv et al. (2019):

$$GDP_t = f(FFC_t, CO2_t, \mu) \quad (1)$$

$$FFC_t = f(CO2_t, GDP_t\mu) \quad (2)$$

$$CO2_t = f(FFC_t, GDP_t\mu) \quad (3)$$

Data from 1960-2019 was obtained from WDI is employed to show the trend of climate change behavior on GDP by investigating the pairwise causality between CO_2 emissions and GDP for LIC and HIC. Granger (1969) presents an endogenous model that captured a lagged-two equation to explain causality. Hence, this study follows that model by making adjustments viz. The modification in this study is on the environment-growth causality:

$$CO2_t = \alpha_1 RGDP_{t-i} + \alpha_2 CO2_{t-j} + \mu_{1t} \quad (4)$$

$$RGDP_t = \alpha_3 RGDP_{t-i} + \alpha_4 CO2_{t-j} + \mu_{2t} \quad (5)$$

$$FFC_t = \alpha_5 RGDP_{t-i} + \alpha_6 FFC_{t-j} + \mu_{3t} \quad (6)$$

$$RGDP_t = \alpha_7 RGDP_{t-i} + \alpha_8 FFC_{t-j} + \mu_{4t} \quad (7)$$

$$CO2_t = \alpha_9 FFC_{t-i} + \alpha_{10} CO2_{t-j} + \mu_{5t} \quad (8)$$

$$FFC_t = \alpha_{11} FFC_{t-i} + \alpha_{12} CO2_{t-j} + \mu_{6t} \quad (9)$$

where $CO2_t = CO2\ emission, \alpha_1 = Parameters, RGDP_{t-i} = Lag\ growth,\ CO2_{t-j} = Lag\ CO2, RGDP_t = Growth, FFC_t = Fossil\ fuel\ consumption, \mu_t = Random\ term$, the model 4-9 was utilized to explain behavior of CO_2, FFC, and growth in LIC and HIC.

Trend Analysis

The trend analyses in **Figure 2-Figure 7** show the relationship between RGDP, FFC, and CO_2 and time between HIC and LIC. **Figure 2-Figure 7** illustrate an upward and downward trend in the hypothesized variable measured as a function of time. The RGDP trend is rising whilst the trend for CO_2 and FFC depicts a declining trend. Our results provide insight into the nature of conflict in policy, which is compelling for further studies in order to establish the flow of causality. The data is a time series and discrete data from 1960-2019. The data groups countries into regional blocks. Due to

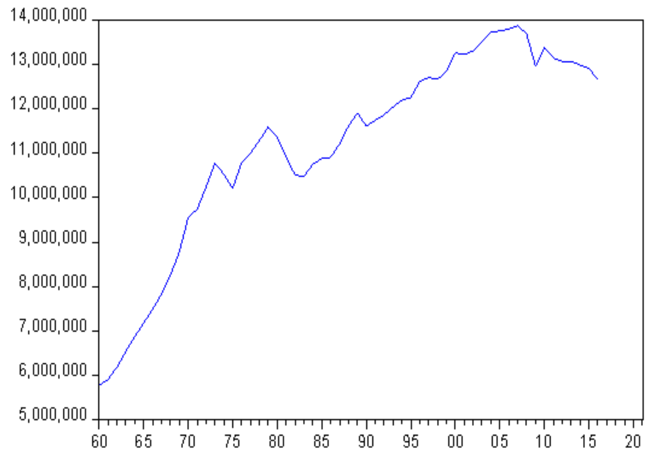

Figure 4. CO_2 in HIC/Time

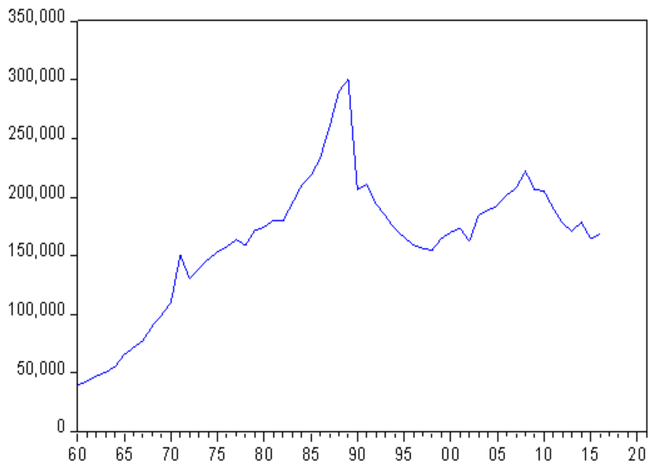

Figure 5. CO_2 in LIC/Time

the nature of the data, the panel causality study will be conducted through a unit root test and lag criteria lenses.

Table 1 presents the overall data behavior used for empirical evaluation. The kurtosis measures the "tailedness" of the probability distribution of a real-valued random variable. The coefficients are mixed, platykurtic <3 and leptokurtic >3. The coefficients of Jerque-Bera are nonnegative. However, the p-value of Jerque-Bera in **Table 1** shows that the data of CO_2 in HIC and FFC in HIC is <0.05%, which implies that the study rejects the normality of the variable. For further tests, the variables were subjected to a unit root test to ascertain their empirical value. The values of CO_2 in HIC and FFC in HIC portray a strong statistical indication of the wide extent of anthropogenic activities in HIC.

Unit Root Test

Table 2 portrays the stationary test for CO_2 in HIC, CO_2 in LIC, GDP in HIC, GDP in LIC, FFC for HIC and LIC, respectively. The augmented Dickey-Fuller (ADF) unit root test results for the hypothesized variables were stationary at 1st differencing. This study adapted the ADF unit root test adjusting for constant and trend, except for fossil FFC. HIC was adjusted for constant (see **Appendix A**).

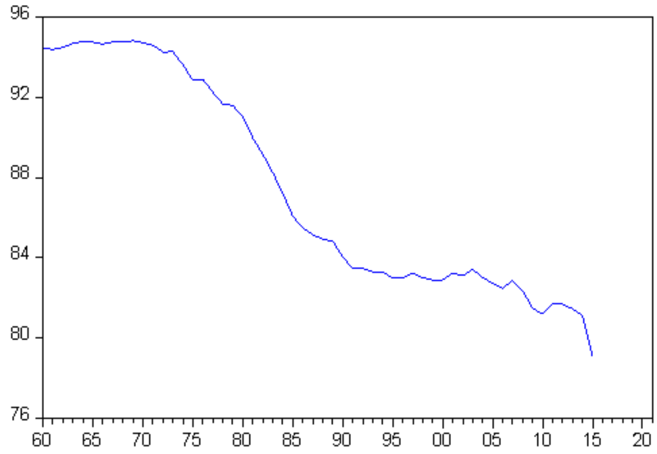

Figure 6. FFC in HIC/Time

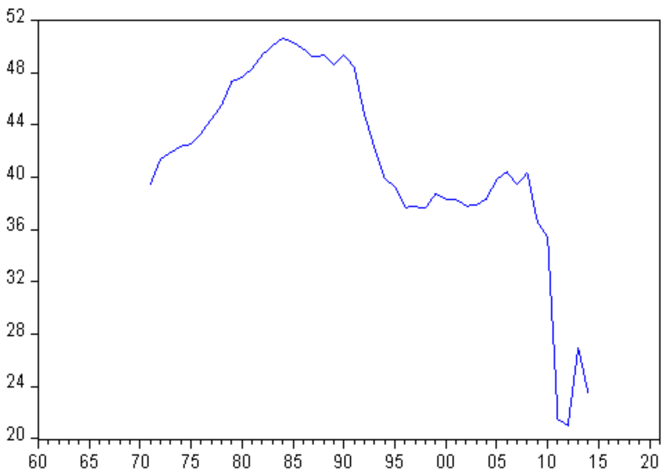

Figure 7. FFC in LIC/Time

Lag Selection

The lag selection criterion was employed to determine the optimal lag based on the lower AIC or SIC coefficients. The study utilized the vector autoregressive system to conduct the optimal lag selection. The optimal lag is 1 based on the most selected lag coefficient. These results are imperative for the causality test and co-integration test. Lag lengths are imputed into the system to avoid an arbitrary lag selection process which could affect the results from the causality test (**Table 3**).

RESULTS AND DISCUSSION

Based on the baseline model (see equations 1-3), the objective of this study is decomposed into components. The causality question is further decomposed into three nexuses namely; FFC and CO_2, CO_2 and RGDP, and FFC and RGDP. Whilst the co-integration question is accommodated in this study to evaluate the long-run problem that affects the climate change and growth nexus.

Table 1. Descriptive statistics for HIC and LIC

	CO2_IN_HIC	CO2_IN_LIC	RGDP_HIC	RGDP_LIC	FOSSIL_FUEL_CONS_HIC	FOSSIL_FUEL_CONS_LIC
Mean	12,472,375	19,6626.4	3.59E+13	2.48E+11	83.59376	40.27728
Median	12,703,774	19,0135.6	3.57E+13	2.08E+11	83.11652	39.44592
Maximum	13,875,576	30,0446.4	4.87E+13	4.57E+11	89.16145	50.63520
Minimum	10,481,422	15,4646.7	2.21E+13	1.59E+11	81.10873	21.01030
SD	1,038,252.	34,690.61	8.36E+12	9.27E+10	1.907725	8.200460
Skewness	-0.485491	1.440264	-0.064612	0.932414	1.292427	-0.750298
Kurtosis	2.050899	4.978221	1.683966	2.469826	4.382193	3.209742
Jarque-Bera	2.534946	16.78985	2.404386	5.168167	11.81390	3.156697
Probability	0.281542	0.000226	0.300534	0.075465	0.002720	0.206316
Sum	4.12E+08	6,488,672.	1.19E+15	8.20E+12	2,758.594	1,329.150
SSD	3.45E+13	3.85E+10	2.24E+27	2.75E+23	116.4613	2,151.922
Observations	33	33	33	33	33	33

Note. SD:Standard deviation; SSD: Sum of squares deviation; Source: Compilations from Eviews 9

Table 2. ADF unit root test

Variables	ADF unit root test (Schwarz inf. criterion)	@1st differencing	
For HIC			
CO_{2t}	Trend and intercept	-6.147537	0.0000
GDP_t	Trend and intercept	-6.179120	0.0000
FFC	Intercept	-3.406077	0.0150
For LIC			
CO_{2t}	Trend and intercept	-7.322588	0.0000
GDP_t	Trend and intercept	-3.728657	0.0330
FFC	Intercept	-6.235634	0.0000

Note. Source: Compilation from Eviews 9

Table 3. VAR lag order selection criterion

Variables	Lag length	LogL
CO_2→RGDP HIC	1	-2,136.921
CO_2→RGDP LIC	1	-1,016.566
FFC→RGDP HIC	1	-1,439.821
FFC→RGDP LIC	1	-775.7102
CO_2→FFC HIC	1	-720.4437
CO_2→FFC LIC	0	-546.6210

Note. Source: Compilation from Eviews 9

To What Extent Does Causality Exist Between FFC and CO_2, CO_2 and RGDP, and FFC and RGDP?

CO_2 and RGDP nexus

This study considered the linkage between CO_2 emissions and RGDP conceptualized in the super-wicked problem hypothesis. The apriori expectation shows that since CO_2 is industry-based, and the industry contributes to RGDP, a reduction in CO_2 emissions would necessarily imply a decline in growth. Hence, there exists an increasing functional relationship in the CO_2 and RGDP nexus. However, data obtained from World Bank Development Indicator between 1960 and 2019 comparatively portrays a uniform relationship between HIC and LIC. The test result connotes that RGDP granger causes CO_2 in HIC and RGDP does not granger cause CO_2 in LIC with p-values of 0.8% and 80%, respectively. On the other hand, CO_2 emissions in HIC and LIC do not granger cause RGDP in HIC and LIC with p-values of 85.7% and 17.6%, respectively. Furthermore, whilst there exists a unidirectional causality in HIC, causality is the absence in LIC between the RGDP and CO_2 emissions nexus.

FFC and CO_2 nexus

The second issue in the super-wicked problem is to determine the role of FFC in determining the level of CO_2 emissions in HIC and LIC. Table 4 presents pairwise granger causality test results for HIC and LIC. The question, therefore, becomes whether FFC has a cause-and-effect relationship with CO_2? From the result above, the study observed that no causality exists between FFC and CO_2 in HIC and LIC. For HIC, the FFC granger causes CO_2 and CO_2 granger cause FFC has p-values of 80.0% and 17.9%, while the FFC granger cause CO_2 and the CO_2 granger cause FFC have p-values of 16.6% and 82.2%, respectively.

FFC and RGDP nexus

The time-series data is necessary to determine the entire industrial processes in HIC and LIC. FFC is an important production input. Hence, there is a positive apriori expectation between FFC and RGDP. In the third relationship, this study observed that there is no causality between FFC and RGDP in HIC and LIC. The p-values coefficients in Table 4 showed that RGDP granger cause FFC and FFC granger cause RGDP in HIC is 81.3% and 90.9%, respectively. Also, in LIC, the p-values show that RGDP granger cause FFC and FFC granger cause RGDP is 63.7% and 17.6%, respectively.

Does Climate Change (Growth) in HIC Affect Growth (Climate Change) in LIC Vice Versa?

Mixed inter-region causality for HIC and LIC

Another debate in the economics of climate change, is whether CO_2 and GDP in HIC and LIC are related? This debate revolves around the CO_2 concentration argument. On the other hand, the debate whether growth spillover in HIC fairly impacts the growth in LIC through technology transfer, etc. This debate is addressed in Table 4.

Table 4. Empirical result from pairwise granger causality for HIC and LIC

Pairwise granger causality tests			
Date: 04/02/21 Time: 02:48			
Sample: 1960 2021			
Lags: 1			
Null hypothesis	**Obs**	**F-statistic**	**Probability**
D(CO2_IN_LIC) does not Granger Cause D(CO2_IN_HIC)	55	0.07278	0.7884
D(CO2_IN_HIC) does not Granger Cause D(CO2_IN_LIC)		0.63823	0.4280
D(RGDP_HIC) does not Granger Cause D(CO2_IN_HIC)	55	7.53960	0.0083
D(CO2_IN_HIC) does not Granger Cause D(RGDP_HIC)		0.03264	0.8573
D(RGDP_LIC) does not Granger Cause D(CO2_IN_HIC)	33	5.82134	0.0222
D(CO2_IN_HIC) does not Granger Cause D(RGDP_LIC)		4.43160	0.0438
D(FOSSIL_FUEL_CONS__HIC) does not Granger Cause D(CO2_IN_HIC)	54	0.05937	0.8085
D(CO2_IN_HIC) does not Granger Cause D(FOSSIL_FUEL_CONS__HIC)		1.84910	0.1799
D(FOSSIL_FUEL_CONS__LIC) does not Granger Cause D(CO2_IN_HIC)	42	0.07295	0.7885
D(CO2_IN_HIC) does not Granger Cause D(FOSSIL_FUEL_CONS__LIC)		0.70944	0.4048
D(RGDP_HIC) does not Granger Cause D(CO2_IN_LIC)	55	0.07410	0.7865
D(CO2_IN_LIC) does not Granger Cause D(RGDP_HIC)		0.02572	0.8732
D(RGDP_LIC) does not Granger Cause D(CO2_IN_LIC)	33	0.06484	0.8007
D(CO2_IN_LIC) does not Granger Cause D(RGDP_LIC)		1.91358	0.1768
D(FOSSIL_FUEL_CONS__HIC) does not Granger Cause D(CO2_IN_LIC)	54	0.82022	0.3694
D(CO2_IN_LIC) does not Granger Cause D(FOSSIL_FUEL_CONS__HIC)		1.02646	0.3158
D(FOSSIL_FUEL_CONS__LIC) does not Granger Cause D(CO2_IN_LIC)	42	1.98690	0.1666
D(CO2_IN_LIC) does not Granger Cause D(FOSSIL_FUEL_CONS__LIC)		0.05082	0.8228
D(RGDP_LIC) does not Granger Cause D(RGDP_HIC)	36	0.03243	0.8582
D(RGDP_HIC) does not Granger Cause D(RGDP_LIC)		0.63618	0.4308
D(FOSSIL_FUEL_CONS__HIC) does not Granger Cause D(RGDP_HIC)	54	0.05655	0.8130
D(RGDP_HIC) does not Granger Cause D(FOSSIL_FUEL_CONS__HIC)		0.01305	0.9095
D(FOSSIL_FUEL_CONS__LIC) does not Granger Cause D(RGDP_HIC)	42	0.01557	0.9013
D(RGDP_HIC) does not Granger Cause D(FOSSIL_FUEL_CONS__LIC)		0.10696	0.7454
D(FOSSIL_FUEL_CONS__HIC) does not Granger Cause D(RGDP_LIC)	32	0.22566	0.6383
D(RGDP_LIC) does not Granger Cause D(FOSSIL_FUEL_CONS__HIC)		0.33208	0.5689
D(FOSSIL_FUEL_CONS__LIC) does not Granger Cause D(RGDP_LIC)	31	0.22698	0.6375
D(RGDP_LIC) does not Granger Cause D(FOSSIL_FUEL_CONS__LIC)		1.91980	0.1768
D(FOSSIL_FUEL_CONS__LIC) does not Granger Cause D(FOSSIL_FUEL_CONS__HIC)	42	0.40894	0.5262
D(FOSSIL_FUEL_CONS__HIC) does not Granger Cause D(FOSSIL_FUEL_CONS__LIC)		0.06925	0.7938

Note. Source: Compilation from Eviews 9

The outcome of the result depicts that RGDP in LIC granger causes CO_2 in HIC and CO_2 in HIC granger cause RGDP in LIC. Thus, there exists a bi-directional causality between RGDP and CO_2 in HIC and LIC. The p-values coefficient showed that RGDP in LIC granger cause CO_2 in HIC is 2.2% and CO_2 in HIC granger cause RGDP in LIC is 4.3%, respectively. Similarly, the coefficient in **Table 4** showed that increasing contribution of CO_2 in HIC does not necessarily affect the CO_2 in LIC vice versa with p-values of 78.8% and 42.8% in HIC and LIC. Hence the CO_2 concentration debate does not hold for HIC and LIC. Hence, from **Figure 1**, the result implies that CO_2 emission in HIC does not determine the CO_2 emissions level in LIC. This also could imply that each region is an independent contributor to CO_2 emissions. Also, the RGDP relationship in HIC and LIC showed no pairwise, and the inter-regional causality amongst FFC and CO_2 in HIC and LIC is basically unrelated and there is no causality. From the result, this study may be far-fetched to determine the technology transfer-growth argument in that HIC does not granger cause growth in LIC with p-values of 85.8% and 43.0%, respectively.

The policy implication of the results in **Table 4** remains that the GDP-climate change nexus is still a subject of contention. The global economy could achieve jointly achieve a low carbon economy as well as high economic growth this is based on their mutually non-exclusive nature. A drastic effort through a robust conscious energy conservation plan and energy-efficient technology is required to insulate the global economy from the inevitable super-wicked phenomenon in order to guarantee an inclusive and sustainable environment-economic growth path. It is obvious that the result does not undermine the existence of either the super-wicked problem or the threat of climate change-time is running out. The study captured the possibilities of achieving high growth with a low carbon economy regime. Hence, the study recommends a new global techno-economic paradigm model that could achieve a high growth rate and low carbon economy simultaneously.

What Is the Long-Run Relationship Between Climate Change and Growth in HIC and LIC?

Co-integration

Johansen system co-integration test was further employed to investigate the existence of a long-run relationship between CO_2, RGDP, and FFC in HIC and LIC. **Table 5** provides a summary of the long-run relationship existing pairwise, *CO_2→RGDP HIC, CO_2→RGDP LIC, FFC→RGDP HIC, FFC→RGDP LIC, and CO_2→FFC LIC.*

From **Table 5**, the coefficient of the trace statistic and max-eigen and its corresponding p-values showed that long-

Table 5. Co-integration

Variables	Trace statistic	Probability	Max-eigen statistic	Probability
CO_2→RGDP HIC	10.72120	0.4136	8.418371	0.5572
	2.302834	0.1291	2.302834	0.1291
CO_2→RGDP LIC	12.82744	0.2520	12.01787	0.2389
	0.809562	0.3682	0.809562	0.3682
CO_2HIC→CO_2 LIC	8.723401	0.6084	5.933146	0.8230
	2.790254	0.0948	2.790254	0.0948
FFC→RGDP HIC	18.18726	0.0535	14.20245	0.1277
	3.984810	0.0459	3.984810	0.0459
FFC→RGDP LIC	5.019888	0.9342	4.995498	0.9029
	0.024391	0.8758	0.024391	0.8758
CO_2→FFC HIC	6.309485	0.8439	5.099993	0.8950
	1.209492	0.2714	1.209492	0.2714
CO_2→FFC LIC	10.95863	0.3927	8.436678	0.5552
	2.521955	0.1123	2.521955	0.1123

Note. Source: Compilation from Eviews 9

run relationship is absent. The p-values in **Table 5** were greater than 5%. Thus, the study accepts the null hypothesis of the non-existence of cointegration. The policy implication of this result in **Table 5** connotes that reduction in CO_2 cannot truncate long-run RGDP goal and fossil fuel energy consumption.

CONCLUSION, POLICY IMPLICATION AND RECOMMENDATION

Firstly, this paper observes unidirectional causality between RGDP and CO_2 in HIC. Conversely, there is an absence of causality between RGDP and CO_2 in LIC. Secondly, this study accepts the null hypothesis that FFC does not granger cause CO_2 in HIC and LIC. Thirdly, the paper rejects the null hypothesis that RGDP in LIC does not granger cause CO_2 in HIC and vice versa. The result showed a bi-directional as well as an inter-country relationship between RGDP and CO_2. Fourthly, based on the findings of this paper, the inter-regional causality between CO_2 in HIC and CO_2 in LIC could not be empirically ascertained. Fifthly, the study found mixed inter-regional and a unidirectional causality between FFC and CO_2. Specifically, the result showed that CO_2 in HIC granger causes FFC in LIC. In terms of interregional causality, there are empirical evidence that showed that RGDP in HIC granger cause RGDP in LIC.

Based on the foregoing empirical evidence, this paper showed that the nexus between FFC, CO_2, and RGDP is weak in HIC and LIC except for inter-regional evidence. The weak existence of casualty between FFC, CO_2 emissions, and RGDP implies that altering the global energy mix, i.e., transmission from fossil-fuel dependency to a green economy should be sensitive without a drastic disruption in the productive structure (model) of the global economy, especially the developing economies.

This study aligns with the conclusion of Kasperowicz (2015), which posits that there is a long-run negative relationship between GDP and CO_2, but only results from HIC support the short-run positive relationship between GDP and CO_2. In this study, the RGDP granger causes CO_2 in HIC. Thus, higher RGDP leads to higher CO_2 in HIC. But the short-run positive relationship between GDP and CO_2 does not hold for LIC.

Evidence provided by Lv et al. (2019) suggestively implies that the connecting link between FFC, CO_2, and RGDP remains a regional problem. The theoretical implication of the result is that the EKC theory based on the result is regional. The paper showed that in HIC, CO_2, and RGGP as an increasing relationship. Unlike in LIC, in the strictest sense, EKC could not hold. Hence, the policy implication is that the super-wicked phenomenon is somewhat regional. Perhaps a country-specific issue. This implies that heterogeneity issues should be properly understood in designing mitigation and NDCs targets.

This paper, therefore, recommends that inclusive mitigation (climate change) policy that supports the heterogeneous structure of the global economy should be enforced to deepen the campaign on meeting the net-zero emission target of 2050. Whilst, mitigation, and adaptation are often a challenge for the global economy, especially for LIC, the traces of inter-regional causality between RGDP in LIC and CO_2 in HIC is a precondition to a long-run presence of a regional super-wicked problem.

This study, therefore, supports IPCC and WMO direction for climate change targeting and policy design to secure the future environment and achieve a sustainable, inclusive, and green economy. Also, this study, recommends, inclusive mitigation and adaptation that would not threaten the short-term growth model but that guarantee global economic stability should be conceptualized and administered. This study is limited by adequate data for a robust regional-mathematical simulation of the causality that sustains the FFC, CO_2, and RGDP nexus.

We encourage to consider a sectoral composition in the FFC, CO_2, and RGDP linkage. In this paper, we assumed away the activities of the sectors in the HIC and LIC. Thus, in the future, scholars should consider nation-wide shocks and causality questions to foster the FFC, CO_2 emission, and RGDP nexus and the debate surrounding the super wicked problem.

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APPENDIX A

Table A1. ADF unit root test – 1

Null hypothesis: D(CO2_IN_HIC) has a unit root				
Exogenous: Constant, linear trend				
Lag length: 0 (Automatic-based on SIC, maxlag=10)				
			t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic			-6.147537	0.0000
Test critical values:	1% level		-4.133838	
	5% level		-3.493692	
	10% level		-3.175693	
*MacKinnon (1996) one-sided p-values				
Augmented Dickey-Fuller test equation				
Dependent variable: D(CO2_IN_HIC,2)				
Method: Least squares				
Date: 03/31/21 Time: 21:47				
Sample (adjusted): 1962 2016				
Included observations: 55 after adjustments				

Table A2. ADF unit root test – 2

Null hypothesis: D(CO2_IN_LIC) has a unit root				
Exogenous: Constant, linear trend				
Lag length: 0 (Automatic-based on SIC, maxlag=10)				
			t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic			-7.322588	0.0000
Test critical values:	1% level		-4.133838	
	5% level		-3.493692	
	10% level		-3.175693	
*MacKinnon (1996) one-sided p-values				
Augmented Dickey-Fuller test equation				
Dependent variable: D(CO2_IN_LIC,2)				
Method: Least squares				
Date: 03/31/21 Time: 21:49				
Sample (adjusted): 1962 2016				
Included observations: 55 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(CO2_IN_LIC(-1))	-1.016439	0.138809	-7.322588	0.0000

Table A3. ADF unit root test – 3

Null hypothesis: D(CO2_IN_HIC) has a unit root				
Exogenous: Constant, linear trend				
Lag length: 0 (Automatic-based on SIC, maxlag=10)				
			t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic			-6.179120	0.0000
Test critical values:	1% level		-4.124265	
	5% level		-3.489228	
	10% level		-3.173114	
*MacKinnon (1996) one-sided p-values				
Augmented Dickey-Fuller test equation				
Dependent variable: D(CO2_IN_HIC,2)				
Method: Least squares				
Date: 03/31/21 Time: 21:52				
Sample (adjusted): 1962 2019				
Included observations: 58 after adjustments				

Table A4. ADF unit root test – 4

Null Hypothesis: D(RGDP_LIC) has a unit root				
Exogenous: Constant, linear trend				
Lag length: 0 (Automatic-based on SIC, maxlag=9)				
			t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic			-3.728657	0.0330
Test critical values:	1% level		-4.234972	
	5% level		-3.540328	
	10% level		-3.202445	
*MacKinnon (1996) one-sided p-values				
Augmented Dickey-Fuller test equation				
Dependent variable: D(RGDP_LIC,2)				
Method: Least squares				
Date: 03/31/21 Time: 21:53				
Sample (adjusted): 1984 2019				
Included observations: 36 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(RGDP_LIC(-1))	-0.585119	0.156925	-3.728657	0.0007

Table A5. ADF unit root test – 5

Null Hypothesis: D(FOSSIL_FUEL_CONS__HIC) has a unit root				
Exogenous: Constant				
Lag length: 0 (Automatic-based on SIC, maxlag=10)				
			t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic			-3.406077	0.0150
Test critical values:	1% level		-3.557472	
	5% level		-2.916566	
	10% level		-2.596116	
*MacKinnon (1996) one-sided p-values				
Augmented Dickey-Fuller test equation				
Dependent variable: D(FOSSIL_FUEL_CONS__HIC,2)				
Method: Least squares				
Date: 04/01/21 Time: 21:50				
Sample (adjusted): 1962 2015				
Included observations: 54 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(FOSSIL_FUEL_CONS__HIC(-1))	-0.502850	0.147633	-3.406077	0.0013
C	-0.160852	0.067553	-2.381104	0.0210
R-squared	0.182407	Mean dependent var		-0.036828
Adjusted R-squared	0.166685	S.D. dependent var		0.458040
S.E. of regression	0.418127	Akaike info criterion		1.130272
Sum squared resid	9.091186	Schwarz criterion		1.203938
Log likelihood	-28.51736	Hannan-Quinn criter.		1.158683
F-statistic	11.60136	Durbin-Watson stat		1.686204
Prob(F-statistic)	0.001278			

Table A6. ADF unit root test – 6

Null Hypothesis: D(FOSSIL_FUEL_CONS__LIC) has a unit root				
Exogenous: Constant, linear trend				
Lag length: 0 (Automatic-based on SIC, maxlag=9)				
			t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic			-6.235634	0.0000
Test critical values:	1% level		-4.192337	
	5% level		-3.520787	
	10% level		-3.191277	
*MacKinnon (1996) one-sided p-values				
Augmented Dickey-Fuller test equation				
Dependent variable: D(FOSSIL_FUEL_CONS__LIC,2)				
Method: Least squares				
Date: 04/01/21 Time: 21:52				
Sample (adjusted): 1973 2014				
Included observations: 42 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(FOSSIL_FUEL_CONS__LIC(-1))	-1.003265	0.160892	-6.235634	0.0000
C	1.639120	1.230909	1.331634	0.1907
@TREND("1960")	-0.061731	0.035015	-1.762971	0.0857
R-squared	0.499300	Mean dependent var		-0.130644
Adjusted R-squared	0.473623	S.D. dependent var		3.651308
S.E. of regression	2.649091	Akaike info criterion		4.855060
Sum squared resid	273.6897	Schwarz criterion		4.979179
Log likelihood	-98.95625	Hannan-Quinn criter.		4.900554
F-statistic	19.44547	Durbin-Watson stat		1.985791
Prob(F-statistic)	0.000001			

Table A7. VAR lag order selection criteria – 1

Endogenous variables: D(CO2_IN_HIC) D(RGDP_HIC)						
Exogenous variables: C						
Date: 04/02/21 Time: 02:10						
Sample: 1960 2021						
Included observations: 51						
Lag	LogL	LR	FPE	AIC	SC	HQ
0	-2146.905	NA	1.36e+34	84.27077	84.34652	84.29972
1	-2136.921	18.79177*	1.08e+34*	84.03613*	84.26341*	84.12298*
2	-2135.149	3.196688	1.17e+34	84.12350	84.50229	84.26825
3	-2133.794	2.337847	1.31e+34	84.22723	84.75754	84.42988
4	-2132.839	1.573448	1.48e+34	84.34663	85.02845	84.60718
5	-2131.872	1.517188	1.67e+34	84.46557	85.29890	84.78401
*Indicates lag order selected by the criterion						
LR: sequential modified LR test statistic (each test at 5% level)						
FPE: Final prediction error						
AIC: Akaike information criterion						
SC: Schwarz information criterion						
HQ: Hannan-Quinn information criterion						

Table A8. VAR lag order selection criteria – 2

Endogenous variables: D(CO2_IN_LIC) D(RGDP_LIC)					
Exogenous variables: C					
Date: 04/02/21 Time: 02:15					
Sample: 1960 2021					
Included observations: 29					
Lag	LogL	LR	FPE	AIC	SC
0	-1029.873	NA	2.76e+28	71.16364	71.25794
1	-1016.566	23.86055*	1.46e+28*	70.52179*	70.80468*
2	-1015.210	2.244587	1.76e+28	70.70413	71.17561
3	-1010.497	7.150103	1.69e+28	70.65499	71.31506
4	-1009.935	0.776081	2.20e+28	70.89204	71.74071
5	-1004.357	6.924079	2.04e+28	70.78324	71.82049
*Indicates lag order selected by the criterion					
LR: sequential modified LR test statistic (each test at 5% level)					
FPE: Final prediction error					
AIC: Akaike information criterion					
SC: Schwarz information criterion					

Table A9. VAR lag order selection criteria – 3

Endogenous variables: D(CO2_IN_HIC) D(FOSSIL_FUEL_CONS__HIC)						
Exogenous variables: C						
Date: 04/03/21 Time: 16:53						
Sample: 1960 2021						
Included observations: 50						
Lag	LogL	LR	FPE	AIC	SC	HQ
0	-727.1275	NA	1.59e+10	29.16510	29.24158*	29.19422
1	-720.4437	12.56547*	1.43e+10*	29.05775*	29.28719	29.14512*
2	-718.6832	3.168930	1.56e+10	29.14733	29.52973	29.29295
3	-714.2705	7.589797	1.54e+10	29.13082	29.66619	29.33469
4	-713.8733	0.651510	1.79e+10	29.27493	29.96326	29.53705
5	-709.1071	7.435257	1.75e+10	29.24428	30.08557	29.56465
*Indicates lag order selected by the criterion						
LR: sequential modified LR test statistic (each test at 5% level)						
FPE: Final prediction error						
AIC: Akaike information criterion						
SC: Schwarz information criterion						
HQ: Hannan-Quinn information criterion						

Table A10. VAR lag order selection criteria – 4

Endogenous variables: D(CO2_IN_LIC) D(FOSSIL_FUEL_CONS__LIC)						
Exogenous variables: C						
Date: 04/03/21 Time: 16:54						
Sample: 1960 2021						
Included observations: 40						
Lag	LogL	LR	FPE	AIC	SC	HQ
0	-546.6210	NA*	2.81e+09*	27.43105*	27.51549*	27.46158*
1	-545.5715	1.941529	3.25e+09	27.57858	27.83191	27.67017
2	-542.9024	4.671004	3.49e+09	27.64512	28.06734	27.79778
3	-542.4915	0.677992	4.19e+09	27.82457	28.41568	28.03830
*Indicates lag order selected by the criterion						
LR: sequential modified LR test statistic (each test at 5% level)						
FPE: Final prediction error						
AIC: Akaike information criterion						
SC: Schwarz information criterion						
HQ: Hannan-Quinn information criterion						

Table A11. VAR lag order selection criteria – 5

Endogenous variables: D(RGDP_HIC) D(FOSSIL_FUEL_CONS__HIC)						
Exogenous variables: C						
Date: 04/03/21 Time: 16:59						
Sample: 1960 2021						
Included observations: 50						
Lag	LogL	LR	FPE	AIC	SC	HQ
0	-1444.867	NA	4.67e+22	57.87469	57.95117*	57.90381*
1	-1439.821	9.487852*	4.48e+22*	57.83282*	58.06226	57.92019
2	-1437.720	3.780105	4.84e+22	57.90882	58.29122	58.05444
3	-1434.361	5.777522	4.98e+22	57.93446	58.46982	58.13833
4	-1433.570	1.297910	5.69e+22	58.06280	58.75113	58.32492
5	-1432.730	1.310992	6.50e+22	58.18919	59.03048	58.50955
*Indicates lag order selected by the criterion						
LR: sequential modified LR test statistic (each test at 5% level)						
FPE: Final prediction error						
AIC: Akaike information criterion						
SC: Schwarz information criterion						
HQ: Hannan-Quinn information criterion						

Table A12. VAR lag order selection criteria – 6

Endogenous variables: D(RGDP_LIC) D(FOSSIL_FUEL_CONS__LIC)						
Exogenous variables: C						
Date: 04/03/21 Time: 17:00						
Sample: 1960 2021						
Included observations: 30						
Lag	LogL	LR	FPE	AIC	SC	HQ
0	-802.0704	NA	6.54e+20	53.60469	53.69811	53.63458
1	-775.7102	47.44845*	1.47e+20*	52.11401*	52.39425*	52.20366*
2	-773.3326	3.962643	1.65e+20	52.22217	52.68924	52.37159
*Indicates lag order selected by the criterion						
LR: sequential modified LR test statistic (each test at 5% level)						
FPE: Final prediction error						
AIC: Akaike information criterion						
SC: Schwarz information criterion						
HQ: Hannan-Quinn information criterion						

Table A13. Cointegration test – 1

Date: 04/03/21 Time: 16:07				
Sample (adjusted): 1962 2016				
Included observations: 55 after adjustments				
Trend assumption: Quadratic deterministic trend				
Series: CO2_IN_HIC RGDP_HIC				
Lags interval (in first differences): 1 to 1				
Unrestricted co-integration rank test (trace)				
Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.141923	10.72120	18.39771	0.4136
At most 1	0.041005	2.302834	3.841466	0.1291
Trace test indicates no co-integration at the 0.05 level				
*Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted co-integrationtion rank test (maximum eigenvalue)				
Hypothesized		Max-Eigen	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.141923	8.418371	17.14769	0.5572
At most 1	0.041005	2.302834	3.841466	0.1291
Max-eigenvalue test indicates no co-integration at the 0.05 level				
*Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted co-integrating coefficients (normalized by b'*S11*b=I):				
CO2_IN_HIC	RGDP_HIC			
5.49E-07	1.00E-12			
1.13E-06	-1.24E-13			
Unrestricted adjustment coefficients (alpha):				
D(CO2_IN_HIC)	-48742.84	-42813.16		
D(RGDP_HIC)	-1.59E+11	-1.98E+10		
1 Co-integrating equation(s):		Log likelihood	-2290.123	
Normalized co-integrating coefficients (standard error in parentheses)				
CO2_IN_HIC	RGDP_HIC			
1.000000	1.82E-06			
	(6.0E-07)			
Adjustment coefficients (standard error in parentheses)				
D(CO2_IN_HIC)	-0.026775			
	(0.01888)			
D(RGDP_HIC)	-87368.47			
	(31319.4)			

Table A14. Low-income countries

Date: 04/03/21 Time: 16:10					
Sample: 1960 2021					
Included observations: 33					
Series: CO2_IN_LIC RGDP_LIC					
Lags interval: 1 to 1					
Selected (0.05 level*) number of co-integrating relations by model					
Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No intercept	Intercept	Intercept	Intercept	Intercept
	No trend	No trend	No trend	Trend	Trend
Trace	0	0	0	0	0
Max-Eig	0	0	0	1	0
*Critical values based on MacKinnon-Haug-Michelis (1999)					
Information criteria by rank and model					
Data trend:	None	None	Linear	Linear	Quadratic
Rank or	No intercept	Intercept	Intercept	Intercept	Intercept
No. of CEs	No trend	No trend	No trend	Trend	Trend
Log likelihood by rank (rows) and model (columns)					
0	-1157.525	-1157.525	-1155.840	-1155.840	-1150.170
1	-1153.607	-1153.564	-1153.220	-1145.816	-1144.161
2	-1153.510	-1151.241	-1151.241	-1143.756	-1143.756
Akaike information criteria by rank (rows) and model (columns)					
0	70.39548	70.39548	70.41453	70.41453	70.19210
1	70.40041	70.45845	70.49818	70.11005	70.07035*
2	70.63696	70.62069	70.62069	70.28824	70.28824
Schwarz criteria by rank (rows) and model (columns)					
0	70.57687	70.57687	70.68662	70.68662	70.55489*
1	70.76320	70.86659	70.95167	70.60888	70.61453
2	71.18114	71.25557	71.25557	71.01382	71.01382

Table A15. Cointegration test – 2

Date: 04/03/21 Time: 16:12				
Sample (adjusted): 1984 2016				
Included observations: 33 after adjustments				
Trend assumption: Quadratic deterministic trend				
Series: CO2_IN_LIC RGDP_LIC				
Lags interval (in first differences): 1 to 1				
Unrestricted co-integration rank test (trace)				
Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.305232	12.82744	18.39771	0.2520
At most 1	0.024234	0.809562	3.841466	0.3682
Trace test indicates no co-integration at the 0.05 level				
*Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted co-integration rank test (maximum eigenvalue)				
Hypothesized		Max-Eigen	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.305232	12.01787	17.14769	0.2389
At most 1	0.024234	0.809562	3.841466	0.3682
Max-eigenvalue test indicates no co-integration at the 0.05 level				
*Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted co-integrating coefficients (normalized by b'*S11*b=I):				
CO2_IN_LIC	RGDP_LIC			
-3.98E-05	1.79E-11			
-2.65E-06	-2.74E-11			
Unrestricted adjustment coefficients (alpha):				
D(CO2_IN_LIC)	9851.554	1412.961		
D(RGDP_LIC)	46963527	7.07E+08		
1 Co-integrating equation(s):		Log likelihood	-1144.161	
Normalized cointegrating coefficients (standard error in parentheses)				
CO2_IN_LIC	RGDP_LIC			
1.000000	-4.50E-07			
	(2.0E-07)			
Adjustment coefficients (standard error in parentheses)				
D(CO2_IN_LIC)	-0.391610			
	(0.13083)			
D(RGDP_LIC)	-1866.850			
	(34123.5)			

Table A16. CO_2 in HIC and CO_2 in LIC

Date: 04/03/21 Time: 16:14				
Sample (adjusted): 1963 2016				
Included observations: 54 after adjustments				
Trend assumption: Quadratic deterministic trend				
Series: CO2_IN_HIC CO2_IN_LIC				
Lags interval (in first differences): 1 to 2				
Unrestricted co-integration rank test (trace)				
Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.104052	8.723401	18.39771	0.6084
At most 1	0.050359	2.790254	3.841466	0.0948
Trace test indicates no co-integration at the 0.05 level				
*Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted co-integration rank test (maximum eigenvalue)				
Hypothesized		Max-Eigen	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.104052	5.933146	17.14769	0.8230
At most 1	0.050359	2.790254	3.841466	0.0948
Max-eigenvalue test indicates no co-integration at the 0.05 level				
*Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted co-integrating coefficients (normalized by b'*S11*b=I):				
CO2_IN_HIC	CO2_IN_LIC			
-9.35E-07	2.92E-05			
1.17E-06	2.82E-06			
Unrestricted adjustment coefficients (alpha):				
D(CO2_IN_HIC)	-9084.738	-56399.99		
D(CO2_IN_LIC)	-5419.727	-432.4728		
1 Co-integrating equation(s):		Log likelihood	-1346.422	
Normalized cointegrating coefficients (standard error in parentheses)				
CO2_IN_HIC	CO2_IN_LIC			
1.000000	-31.22021			
	(11.2465)			
Adjustment coefficients (standard error in parentheses)				
D(CO2_IN_HIC)	0.008495			
	(0.03447)			
D(CO2_IN_LIC)	0.005068			
	(0.00219)			

Table A17. FFC and RGDP in HIC

Date: 04/03/21 Time: 16:37				
Sample (adjusted): 1963 2015				
Included observations: 53 after adjustments				
Trend assumption: Quadratic deterministic trend				
Series: FOSSIL_FUEL_CONS__HIC RGDP_HIC				
Lags interval (in first differences): 1 to 2				
Unrestricted co-integration rank test (trace)				
Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.235070	18.18726	18.39771	0.0535
At most 1 *	0.072428	3.984810	3.841466	0.0459
Trace test indicates no co-integration at the 0.05 level				
*Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted co-integration rank test (maximum eigenvalue)				
Hypothesized		Max-Eigen	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.235070	14.20245	17.14769	0.1277
At most 1 *	0.072428	3.984810	3.841466	0.0459
Max-eigenvalue test indicates no co-integration at the 0.05 level				
*Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted co-integrating coefficients (normalized by b'*S11*b=I):				
FOSSIL_FUEL_CONS__HIC	RGDP_HIC			
-0.747645	1.33E-12			
0.362615	7.09E-13			
Unrestricted adjustment coefficients (alpha):				
D(FOSSIL_FUEL_CONS__HIC)	0.176043	-0.045568		
D(RGDP_HIC)	-4.06E+10	-1.14E+11		
1 Co-integrating equation(s):		Log likelihood	-1513.343	
Normalized cointegrating coefficients (standard error in parentheses)				
FOSSIL_FUEL_CONS__HIC	RGDP_HIC			
1.000000	-1.77E-12			
	(4.3E-13)			
Adjustment coefficients (standard error in parentheses)				
D(FOSSIL_FUEL_CONS__HIC)	-0.131618			
	(0.03967)			
D(RGDP_HIC)	3.04E+10			
	(4.8E+10)			

Table A18. FFC and RGDP in LIC

Date: 04/03/21 Time: 16:41				
Sample (adjusted): 1984 2014				
Included observations: 31 after adjustments				
Trend assumption: Quadratic deterministic trend				
Series: FOSSIL_FUEL_CONS__LIC RGDP_LIC				
Lags interval (in first differences): 1 to 1				
Unrestricted co-integration rank test (trace)				
Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.148831	5.019888	18.39771	0.9342
At most 1	0.000786	0.024391	3.841466	0.8758
Trace test indicates no co-integration at the 0.05 level				
*Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted co-integration rank test (maximum eigenvalue)				
Hypothesized		Max-Eigen	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.148831	4.995498	17.14769	0.9029
At most 1	0.000786	0.024391	3.841466	0.8758
Max-eigenvalue test indicates no co-integration at the 0.05 level				
*Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted co-integrating coefficients (normalized by b'*S11*b=I):				
FOSSIL_FUEL_CONS__LIC	RGDP_LIC			
-0.310031	-1.72E-11			
0.122941	-2.82E-11			
Unrestricted adjustment coefficients (alpha):				
D(FOSSIL_FUEL_CONS__LIC)	0.945490	-0.039616		
D(RGDP_LIC)	3.59E+08	-1.11E+08		
1 Co-integrating equation(s):		Log likelihood	-793.8955	
Normalized co-integrating coefficients (standard error in parentheses)				
FOSSIL_FUEL_CONS__LIC	RGDP_LIC			
1.000000	5.54E-11			
	(4.9E-11)			
Adjustment coefficients (standard error in parentheses)				
D(FOSSIL_FUEL_CONS__LIC)	-0.293131			
	(0.16210)			
D(RGDP_LIC)	-1.11E+08			
	(2.5E+08)			

Table A19. CO_2 and FFC in HIC

Date: 04/03/21 Time: 16:44				
Sample (adjusted): 1962 2015				
Included observations: 54 after adjustments				
Trend assumption: Quadratic deterministic trend				
Series: CO2_IN_HIC FOSSIL_FUEL_CONS__HIC				
Lags interval (in first differences): 1 to 1				
Unrestricted co-integration rank test (trace)				
Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.090122	6.309485	18.39771	0.8439
At most 1	0.022149	1.209492	3.841466	0.2714
Trace test indicates no co-integration at the 0.05 level				
*Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted co-integration rank test (maximum eigenvalue)				
Hypothesized		Max-Eigen	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.090122	5.099993	17.14769	0.8950
At most 1	0.022149	1.209492	3.841466	0.2714
Max-eigenvalue test indicates no co-integration at the 0.05 level				
*Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted co-integrating coefficients (normalized by b'*S11*b=I):				
CO2_IN_HIC	FOSSIL_FUEL_CONS__HIC			
-7.87E-07	-0.441671			
1.03E-06	-0.473813			
Unrestricted adjustment coefficients (alpha):				
D(CO2_IN_HIC)	66115.78	-19001.99		
D(FOSSIL_FUEL_CONS__HIC)	0.098880	0.034542		
1 Co-integrating equation(s):		Log likelihood	-768.5738	
Normalized cointegrating coefficients (standard error in parentheses)				
CO2_IN_HIC	FOSSIL_FUEL_CONS__HIC			
1.000000	560906.0			
	(368133.)			
Adjustment coefficients (standard error in parentheses)				
D(CO2_IN_HIC)	-0.052061			
	(0.02765)			
D(FOSSIL_FUEL_CONS__HIC)	-7.79E-08			
	(4.4E-08)			

Table A20. CO_2 and FFC in LIC

Date: 04/03/21 Time: 16:45				
Sample (adjusted): 1974 2014				
Included observations: 41 after adjustments				
Trend assumption: Quadratic deterministic trend				
Series: CO2_IN_LIC FOSSIL_FUEL_CONS__LIC				
Lags interval (in first differences): 1 to 2				
Unrestricted co-integration rank test (trace)				
Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.185982	10.95863	18.39771	0.3927
At most 1	0.059657	2.521955	3.841466	0.1123
Trace test indicates no cointegration at the 0.05 level				
*Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted co-integration rank test (maximum eigenvalue)				
Hypothesized		Max-Eigen	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.185982	8.436678	17.14769	0.5552
At most 1	0.059657	2.521955	3.841466	0.1123
Max-eigenvalue test indicates no co-integration at the 0.05 level				
*Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted co-integrating coefficients (normalized by b'*S11*b=I):				
CO2_IN_LIC	FOSSIL_FUEL_CONS__LIC			
-4.44E-05	0.148725			
2.16E-05	-0.332238			
Unrestricted adjustment coefficients (alpha):				
D(CO2_IN_LIC)	7308.729	-1416.423		
D(FOSSIL_FUEL_CONS__LIC)	0.492599	0.521443		
1 Co-integrating equation(s):		Log likelihood	-549.3754	
Normalized cointegrating coefficients (standard error in parentheses)				
CO2_IN_LIC	FOSSIL_FUEL_CONS__LIC			
1.000000	-3346.844			
	(1888.97)			
Adjustment coefficients (standard error in parentheses)				
D(CO2_IN_LIC)	-0.324780			
	(0.12463)			
D(FOSSIL_FUEL_CONS__LIC)	-2.19E-05			
	(1.8E-05)			

Table A21.

Date: 04/03/21 Time: 16:02					
Sample: 1960 2021					
Included observations: 54					
Series: CO2_IN_HIC RGDP_HIC					
Lags interval: 1 to 2					
Selected (0.05 level*) number of co-integrating relations by model					
Data trend:	None	None	Linear	Linear	Quadratic
Test type	No intercept	Intercept	Intercept	Intercept	Intercept
	No trend	No trend	No trend	Trend	Trend
Trace	2	2	0	0	0
Max-Eig	2	2	0	0	0
*Critical values based on MacKinnon-Haug-Michelis (1999)					
Information criteria by rank and model					
Data trend:	None	None	Linear	Linear	Quadratic
Rank or	No intercept	Intercept	Intercept	Intercept	Intercept
No. of CEs	No trend	No trend	No trend	Trend	Trend
Log likelihood by rank (rows) and model (columns)					
0	-2268.3811	-2268.3811	-2258.4186	-2258.4186	-2252.2463
1	-2257.2441	-2257.2419	-2251.4071	-2249.8720	-2248.7097
2	-2255.0320	-2251.2727	-2251.2727	-2247.2632	-2247.2632
Akaike information criteria by rank (rows) and model (columns)					
0	84.31041	84.31041	84.01551	84.01551	83.86098*
1	84.04608	84.08304	83.90397	83.88415	83.87814
2	84.11230	84.04714	84.04714	83.97271	83.97271
Schwarz criteria by rank (rows) and model (columns)					
0	84.60508	84.60508	84.38384	84.38384	84.30297*
1	84.48808	84.56187	84.941963	84.43665	84.46747
2	84.170163	84.71013	84.71013	84.70937	84.70937