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Heterogeneous Analysis of Pollution Abatement via Renewable and Non-Renewable Energy: Lessons from Investment in G20 Nations

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Abstract

This study analyses the role of renewable and non-renewable energy in pollution reduction through the capital investment channel in G20 economies between 1990 and 2017. We consider cross-sectional dependence since the countries are heterogeneous and cross-sectionally dependent using the pooled mean group approach. Findings reveal that renewable energy negatively impacts carbon emissions in both the short- and long-run, while non-renewable energy positively affects carbon emissions in both the short- and long-run. Again, results show that capital investment lowers pollution in the short-run but increases it in the long-run. Lastly, we find that capital investment interacts with renewable energy to reduce pollution in both short- and long-run, while its interaction with non-renewable energy expands pollution in both short- and long-run. We, therefore, conclude that capital investment provides an important channel to reduce pollution in G20 nations and recommend that if energy consumption is to work through the capital investment channel to lower pollution in the G20, the proportion of renewable energy must increase relative to non-renewable energy in their energy mix.

JEL Classification: Q41; Q42; Q53; F23; O50.

1. Introduction

The rising concerns about global warming and climate change necessitate the call by the UNFCCC[1] for countries to curb warming. The Paris Agreement, which built on the convention charts a new direction for nations to keep warming below 2^0C and then limit it to 1.5^0C. Climate change poses an enormous threat to ecosystems' health, and it has severe implications on human lives (Kerr, 2007; Yao *et al.,* 2015). The fact that human activities provide an impetus for climate change through the carbon emissions generated from fossil fuels consumption cannot be overemphasised. According to the International Panel on Climate Change (IPCC), about 90% of climate change is caused by human activities, which remains its main causal factor up to date (IPCC, 2015). Moreover, Hughes *et al.* (2003), Patz *et al.* (2005), and McMichael *et al.* (2006) traced the climate change impacts to the green-house-gas (GHGs) emissions from human activities. As opined in Yao *et al.* (2015), from the 19th century to date, production activities in developed countries (DCs) account for about two-thirds of the CO_2 emissions from energy consumption. These energy-related CO_2 emissions are associated with heavy-duty machines, high-performance vehicles and other fossil fuels consuming production plants in these countries. It implies that most of the GHGs emissions that are generated globally can be attributed to the activities of the G20 economies. For instance, Yao *et al.* (2015) affirmed that G20 countries housed about 67% of the world's population, produced 86% of the world's output and generated 76% of world's CO_2 emissions in 2010. Similarly, evidence from the International Energy Agency (IEA) suggests that in 2014, G20 nations accounted for about 85% of the world economy, two-thirds of the world population, and 75% of the global trade. They also had the most reliance on non-renewable energy with 77% of global energy use, and accounted for 82% of the world energy-related CO_2 emissions (IEA, 2018).

It therefore implies that G20[2] economies, which comprises the European Union, twelve emerging nations, and seven developed countries, are credited with a high level of output growth. Such a huge growth process is attributable to the capital investment in their domain, thereby making several of them highly industrialised. For instance, the United States (US), Germany, Canada, Australia, and Saudi Arabia are heavily industrialised and contribute significantly to global emissions. In 2016, the US is credited with the largest amount of CO_2 emissions at 5,186,168,427 metric kilotons (MKT), followed by India, Russia, and Japan with 2,034,752,294 MKT, 1,789,074,295 MKT, and 1,243,384,358 MKT respectively. Next is China, Germany, Korea, and Saudi Arabia with emissions of 1,024,946,302 MKT, 757,312,507 MKT, 592,499,192 MKT, and 541,428,883 MKT respectively (Statista, 2018). Moreover, In 2016 fossil fuel energy use per total energy and CO_2 emissions correspondingly stood at 85.3% and 5,350.4 million tonnes (MT) for the US, 80.8% and 760.8 MT for Germany, 63.5% and 527.4 MT for Canada, 93.2% and 408.9 MT for Australia, as well as, 99.9% and 621.8 MT respectively for Saudi Arabia (BP Statistical Review, 2018). Hence, having confirmed that energy use causes GHGs emissions (see, Inglesi-Lotz & Dogan, 2018; Dogan & Seker, 2016; Mesagan *et al,* 2019), and carbon-intensive machines promote global warming (see, Blomquist and Cave, 2008; Tang & Tan, 2015; Mesagan, 2015; Zhang and Zhou 2016; Haider *et al.* 2019), the need to focus on the G20 nations.

Moreover, the empirical literature on the energy-pollution link are mixed. For instance, Stolyarova (2013) and Wang *et al.* (2013) confirmed that non-renewable energy negatively impacts carbon emissions. However, Soytas *et al* (2007), Halicioglu (2009), Zhang & Cheng (2009), Shahbaz *et al* (2013), Shafiei & Salim (2014), Cowan *et al* (2014), Yao *et al.* (2015), Bento & Moutinho (2016), Li *et al* (2017), Shahsavari & Akbari (2018), Mesagan & Nwachukwu (2018), Inglesi-Lotz & Dogan (2018), Chen *et al.* (2019), Sharif *et al.* (2019), Mesagan *et al* (2019), Xian *et al.* (2019) showed evidence of non-renewable energy consumption increasing the pollution level. In terms of the channels of transmission to pollution, studies like Pata (2018), Mesagan & Nwachukwu (2018), Khan *et al.* (2018), Baloch *et al.* (2019), Sharif *et al.* (2019), and Charfeddine & Kahia (2019) identified that energy affects pollution through the financial development channels. Meanwhile, studies like Frankel & Rose (2005), Li *et al* (2015), Wang *et al.* (2013), Yao *et al.* (2015), Pata (2018), Xian *et al.* (2019), and Haider *et al.* (2019) attributed increases in pollution to factors like urbanisation, trade, and population growth. Specifically, both Frankel & Rose (2005), and Li *et al* (2015) posited that trade can affect environmental pollution through the polity channel, while Shafiei & Salim (2014), Inglesi-Lotz & Dogan (2018), Chen *et al.* (2019), and Sharif *et al.* (2019) provided evidence that pollution can only be reduced through the renewable energy channel in the pollution abatement model.

Therefore, since empirical literature is imprecise, and there is the need to fashion alternative channel for improving the energy-pollution link among G20 nations, this study becomes expedient. One channel identified in the literature is capital investment (See, Sims, Rogner & Gregor, 2003; Tang & Tan, 2015), which can offset the threats of CO_2 pollution through the technique effect it creates. However, it has received less attention from previous related studies, especially those focusing on G20 nations that have a massive amount of industrial productivity and carbon pollution. This paper is very important in addressing the energy-pollution problem via the channel of capital investment. At this present time, we cannot overemphasise its justification as the G20 nations are faced with fulfilling their bargain of the Paris Agreement without lowering their productivity despite a persistent increase in CO_2 emissions. Consequently, its main thrust is to analyse the role of energy in CO_2 pollution via the capital investment channel in the G20. Specifically, the study determines the effect of non-renewable and renewable energy use on pollution. It examines the impact of capital investment on pollution, and then analyses the impact of both energy sources on pollution through the investment channel. This study extends the frontiers of knowledge in four ways. Firstly, we disaggregate the sources of energy consumed to identify the main cause of pollution in G20 in the short-run and in the long-run, and we find non-renewable energy culpable. Secondly, we assess the role of capital investment in the G20's pollution abatement model, in both the short- and long-run, and confirm that it is crucial, especially in the short-run. Thirdly, we identify capital investment as the augmenting channel for reducing G20's pollution resulting from non-renewable energy, but with the condition that the share of renewable energy rises in the mix. Lastly, we employ the heterogeneous and dynamic panel analysis to generate panel estimates for the short- and long-run. Our subsequent findings consider cross-sectional dependence having confirmed that G20 nations are dependent cross-sectionally and have heterogeneous features also.

Regarding the structure of the study, we organize the remaining sections as: section 2 presents the facts on alternative energy usage and carbon pollution in G20; section three covers the research methodology; section four covers the result, and section five presents the conclusion.

[1] United Nations Framework Convention on Climate Change. The 2018 edition was held in Katowice, Southern Poland, between 2nd and 14th November 2018 while the last edition was held in Bonn, Western Germany, between 17th and 27th June 2019.
[2] The members of the G20 includes the European Union, twelve emerging nations (Indonesia, Brazil, South Africa, South Korea, Russia, China, Turkey, Argentina, Mexico, Saudi Arabia, India, and Australia), and seven developed countries (Italy, Japan, the United Kingdom, Canada, France, Germany, and the United States).

2. Facts On Alternative Energy Use And Carbon Pollution In G20

2.1 Carbon Emission and Energy Usage by Types of Fuel

In Table 1, we present the relationship between energy consumption by fuel type and CO_2 emissions in G20 economies. For several countries in G20, available evidence shows that there is an association between fossil fuel energy consumption and pollution.

Table 1: Energy Use by Fuel Type and Carbon Pollution in G20 Countries

Countries	Energy Consumption (% of Total)				CO_2 Emissions (Million Tonnes)	
	Fossil Fuels	Renewables	Fossil Fuels	Renewables		
	2015		2016		2015	2016
Italy	83.5	16.5	84.0	16.0	336.2	336.9
Japan	92.2	7.8	90.8	9.2	1206.6	1191.2
UK	81.8	18.2	81.4	18.6	433.4	406.4
Canada	64.4	35.6	63.5	36.5	531.6	527.4
France	50.3	49.7	52.1	47.9	309.7	316.0
Germany	80.1	19.9	80.8	19.2	751.1	760.8
United States	86.1	13.9	85.3	14.7	5445.0	5350.4
Indonesia	96.7	3.3	96.7	3.3	492.5	531.4
Brazil	66.7	33.3	63.2	36.8	491.3	458
Saudi Arabia	99.96	0.04	99.96	0.04	611.7	621.8
Australia	94.3	5.7	93.2	6.8	413.6	408.9
Russia	87.9	12.1	87.2	12.8	1521.9	1490.1
South Korea	85.2	14.8	85.5	14.5	654.0	662.1
India	92.5	7.5	92.5	7.5	2157.4	2271.1
Turkey	85.5	14.5	85.2	14.8	343.0	361.0
China	88.2	11.8	87.0	13.0	9164.5	9123
Argentina	86.8	13.2	87.3	12.7	193.4	194.3
Mexico	93.0	7.0	92.9	7.1	481.4	470.3
South Africa	96.5	3.5	95.3	4.7	421.8	425.7
EU	75.1	24.9	75.4	24.6	3477.0	3485.1

Source: *Compiled from the BP Statistical Review (BPS, 2018)*

As presented in Table 1, in 2015, Brazil consumed 66.7% of fossil fuel energy and 33.3% of renewable energy, but in 2016, it increased its renewable energy to 36.8% and was able to lower its CO_2 emissions to 458 MT from the initial 491.3 MT. Increases in the production of biofuels on a large scale enable Brazil to achieve this significant reduction in carbon emissions. Between 2015 and 2016, Russia increased its renewable energy use from 12.1% to 12.8% while its CO_2 emissions reduced to 1490 MT from the initial 1521.9 MT. Both China and the United Kingdom marginally increased their renewable energy consumed from 11.8% to 13.0% and from 18.2% 18.6% respectively. Both countries were able to slightly lower their CO_2 emissions from 9164 MT to 9123 MT, and from 433.4 MT to 406.4 MT between 2015 and 2016 respectively. Italy increased its fossil energy use marginally from 83.5% to 84.0% between 2015 and 2016, and its CO_2 emissions rose from 336.2 MT to

336.9 MT. The situation is more evident with Japan, which increased renewable energy use from 7.8% to 9.2% while its emissions of carbon significantly dropped from 1206.6 MT to 1191.2 MT between 2015 and 2016.

For France, which generated substantial amount from renewable energy sources, evidence in Table 1 suggests that efforts to increase fossil fuel energy from 50.3% to 52.1% caused CO_2 emissions to significantly rise from 309.7 MT to 316.0 MT between 2015 and 2016. The United States follow similar trends as its CO_2 emissions dropped from 5445 MT to 5350 MT as fossil fuel energy fell from 86.1% to 85.3% between 2015 and 2016. The other G20 countries that improve on their CO_2 emissions' situation as they reduced their fossil fuel energy consumption include Mexico, Australia and Canada. However, South Africa marginally increased renewable energy use from 3.5% in 2015 to 4.7% in 2016 and the country recorded a slight increase in CO_2 emissions to 425.8 MT from the initial 421.7 MT. India's CO_2 emissions rose to 2271.1 MT from 2157.4 MT between 2015 and 2016 despite maintaining the same ratio of 7.5% in renewable energy use. Also, the EU increased non-renewable energy use from 75.1% to 75.4% between 2015 and 2016, while its CO2 emissions increased from 3477 MT to 3485.1 MT for the two years. Moreover, other G20 economies that increased both non-renewable energy and CO_2 emissions include Argentina, South Korea, and Germany. Then, Indonesia, Saudi Arabia, and India maintained the same ratio of fossil energy use for the two years and recorded increases in their CO_2 emissions.

2.2 The Link between Fossil Fuel Energy Use and Environmental Quality

The framework presented in Figure 1 depicts the mediating role capital investment plays in influencing CO_2 emissions in G20 nations. With Figure 1, we graphically depict how renewable and non-renewable energy use can be used to curtail and increase the volumes of carbon emissions among the G20 countries. As described in Fig. 1, with extant amount of renewable and non-renewable energies in the G20 energy mix, the situation with CO_2 pollution in G20 will be altered. For instance, experience has shown that if the energy mix contains more fossil fuel energy, volume of emissions of carbon would increase and vice versa (see, Dogan & Seker, 2016; Mesagan, Isola & Ajide, 2019; Chen *et al.,* 2019).

Contrarywise, CO_2 emissions can be lowered when companies either use low carbon-emitting machines during production activities or when they generate energy from renewable sources. As suggested in Mesagan *et al.* (2019), the attraction of appropriate technologies of production is beneficial for countries to lower CO_2 emissions. Moreover, Fig. 1 supports the notion that capital investment inflow helps to increase output growth in G20, which can then negatively or positively affect the environmental quality (Safdari *et al.,* 2013; Bernard *et al.,* 2004). To substantiate this, Eregha & Mesagan (2017) affirmed that energy consumption enhances output growth, Bernard *et al.* (2004) opined that investment and output growth reduce environmental damage, while Safdari *et al.* (2013) revealed that increased income and investment worsened environmental degradation. Also, the Environmental Kuznets Curve (EKC) suggested the existence of a reversed U-shaped association between income and emission levels (see, Andreoni & Levinson, 2001; Stern, 2004). This informs the double-barrel effect of income on carbon pollution in Fig. 1. Bernard *et al.* (2004) affirmed that with strong regulations, only environmentally-friendly capital investments would be attracted to generate the technique effect that will lower CO_2 emissions. However, when highly carbon-laden plants are attracted, the composition effect of emissions is expected to increase, and CO2 emissions increase also. Therefore, for G20 economies to lessen CO_2 pollution to achieve their respective Paris agreement goals, capital investment can provide the appropriate channel.

2.3 Dissecting the Plans for curbing Carbon Emissions in G20 Economies

According to Wilson (2014), energy usage and pollution in China increased significantly from the early 2000s, thereby making it overtake the US in 2007 as the country with the most considerable amount of carbon emissions globally. Specifically, in 2002, China's CO_2 emission was about half lesser than the CO_2 emissions in America. By 2012, its CO_2 emission has doubled those in America and has surpassed emissions generated in the EU. Over the period, the Chinese authorities developed a short-term energy-intensity reduction target, which covers between 2006 and 2010 to reduce the country's CO_2 emissions and energy intensity. Furthermore, China established another long-term CO_2 emissions reduction target for the year 2020 (Zhou *et al.,* 2011). Besides, the industrial sector in China contributed over 50 percent of its energy utilised (Grubb *et al.,* 2015).

According to the Australian Government's Department of Environment and Energy (DEE, 2017), Australia is among the 178 countries with less than 2% of emissions but jointly contribute about 40% of total emissions in the world. Having ratified the first commitment of the Kyoto Protocol, the country reduced emissions by 128 MT between 2008 and 2012. Meaning that the country is well ahead to achieve its 2030 target of reducing emissions by between 26% to 28% below 2005 level. However, CAT (2019) opined that based on total country-wide emissions and lack of accelerated climate action policies, Australia might substantially increase its GHGs emissions between 8% and 16% above 2005 levels by 2030.

Again, Mazumdaru (2017) reports that India's CO_2 emission per person is about 33% of the global average due to its energy sector's 60% dependence on coal. However, the country's emission is lesser than those of China and the US. Moreover, in terms of total GHGs emissions, India follows directly behind China, the United States, and the EU with about 4.5% of GHGs concentrations. The high pace of industrial production increased the country's non-renewable energy consumption. Hence, to lower GHGs emissions, to between 33% and 35% of GDP by 2030, the country plans to diversify its energy mix. This will enable India to generate about 175 gigawatts (GW) from renewable sources like solar by 2022 and increase its renewable energy up to 40% of total energy by 2030. During this period, only battery-driven and electric vehicles will be permitted in India (Mazumdaru, 2017; CAT, 2019). In 2016, Canada announced its framework on clean growth and climate with measures to ease out old coal plants and establish a carbon pricing plan. The Canadian NDC goal for 2030 is to lower emissions by about 30% below its 2005 level (CAT, 2019). However, climate action tracker opines that Canada may find it tough in achieving its 2030 Paris Agreement target, unless it depends on carbon sinks in the wetlands, forests, and soils, while also sacrificing its growth target.

Moreover, Russia has always experienced considerable increases in foreign exchange earnings due to the increases in world crude oil price of the early 2000s. It is among the largest carbon-emitting nations in the whole world. To reduce emission intensity, Climate Action Tracker (2019) reports that Russia set up a national policy on climate change. Although its Intended Nationally Determined Contribution's (INDC) target for reducing pollution exceeds the Paris Agreement's level, it is still among the weakest by any country. Hence, it may affect the country's quest to lower carbon emissions by 2030 to below 70% of levels in 1990. According to Kuramochi (2014), the Japanese government has redesigned its energy policy for combating climate change after the March 2011 Fukushima nuclear disaster. To this end, in 2013, the country set up a new emissions reduction target of 3.8% from the 2005 level to replace the earlier 25% targeted reduction from 1990 standard that was set in Copenhagen in 2009. However, CAT (2019) opined that the plan of the country to construct coal plants could be risky to the climate change mitigation efforts of the Japanese government. Furthermore, the ability of the country to build new nuclear reactors could also prove crucial in achieving its 2030 emissions reduction target.

The Brazilian government employ different strategies to reduce emissions and improve global warming. The country produces biofuel and most especially ethanol to diversify its sources of energy and lowers pollution (Masiero, 2011). To increase its renewable energy mix and reduce emissions, the country established plants to produce ethanol-driven vehicles on a large-scale in 1979. However, the current deforestation in the country since 2016 coupled with government's reduction of finances by half to its Environment Ministry, increased the country's emission for the current period (CAT, 2019). For the United States, CAT (2019) reported that wind and solar rose significantly in contribution while about 6.3 GW of coal-firing plants shut down in 2017. The resultant effect of this effort is that fossil fuel energy dropped for the first time in 2017 in the US since the global financial crisis of 2008. However, decarbonising the US and limiting global warming to 2^0C may be unrealistic due to the threat from Donald Trump's administration to remove the country from the Agreement.

The German government announced 'Energiewende', which is an ambitious energy transition plan to decarbonise the economy in 2010. With Energiewende, the country aims to lower GHG emissions by 40% below 1990 levels by 2020, which is more ruthless than the European Union's 20% targeted reduction by 2020 and a further 40% below 1990 levels by 2030 (Hope, 2014; Appunn, 2018). Furthermore, another 95% emissions reduction target below 1990 levels is set for 2050 in the plan. To achieve this set target, the country plans to increase its renewable energy by about 60% and make renewable energy to contribute over two-thirds of its energy consumption in 2050 (Appunn, 2018). One major challenge with the German plan for 2020 emissions reduction is that the country still requires some conventional power source, like coal, to run together with its

renewables. Hence, phasing out its nuclear power might not be realistic in 2020. For South Africa, the country established an Integrated Resource Electricity Plan (IRP) to increase its renewable energy for 2030 (CAT, 2019). The robust renewable energy target that IRP set to be achieved in 2030 is 17.8 GW. Also, between 2025 and 2030, the country's Nationally Determined Contribution (NDC) has targeted reducing emissions to between 398 MT and 614 MT. The Climate Action Tracker (2019) noted that economic recession, which slows the pace of economic growth, and the current national policies, might enhance its quest to achieve its set 2030 targets. However, the recent transition in government that stalled the signing of power purchase agreement with renewable energy firms, the uncertainty in the starting date to levy CO_2 pollution tax, and the expected rise in the number of coal plants currently under construction might hinder its 2030 climate change target (CAT, 2019; Mesagan *et al.,* 2019).

3. Research Methodology

This study leans on the proposition of the EKC that posits a long-run beneficial link between pollution and income. Thus, following the models specified in Andreoni & Levinson (2001) and Stern (2004), we specify the model between CO_2 emissions and income, together with other drivers like energy use, while accounting for capital investment as the mediating variable. Hence, using capital investment as a pollution reduction channel is vital owing to the technique effect that environmentally friendly technologies generate. That is, even when energy use is emission-laden, capital investment can create the technique effect to neutralise the threats of CO_2 emissions as suggested in the pollution hallo theory. Therefore, the empirical model is analysed using the Pooled Mean Group (PMG) approach. The framework is developed by Pesaran, Shin & Smith (1999) for handling samples that are heterogeneous. The PMG is more appropriate because of its capability in analysing cross-country studies with large number of cross-section (N) and large series (T). This is the preference it enjoys over the GMM framework that can only accommodate large N and small T dimension (Pesaran & Smith, 1995; Pesaran et al. 1999).

Hence, given the model in Eq. (1):

$$a_i(L)y_{it} = b_i(L)x_{it} + d_i z_{it} + e_{it} \tag{1}$$

For country *i*, where *i=1,..,N.* long-run estimate is $\theta_i = \frac{b_i(1)}{d_i(1)}$.

For the Pooled Mean Group approach, the short-run parameters are varied across samples while long-run estimates remain similar across the sample. Therefore, the unrestricted PMG condition for $country\ i = 1,2,...N, and\ period\ t = 1,2,...T$ for the dependent variable *y* becomes:

$$y_{it} = \sum_{j=1}^{q} \omega_{ij} y_{i,t-j} + \sum_{j=0}^{p} \gamma'_{ij} x_{i,t-j} + \mu_i + \varepsilon_{it} \tag{2}$$

Where, x_{ij}=kx1 vector of regressors for panel $i\ and\ \mu_i = fixed\ effects$

We then represent Eq. (2) in a VECM structure using a process of re-parameterisation as:

$$\Delta y_{it} = \theta_i\left(y_{i,t-1} - \varphi'_i x_{i,t-1}\right) + \sum_{j=1}^{q-1} \omega_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{p-1} \gamma'_{ij} x_{i,t-j} + \mu_i + \varepsilon_{it} \tag{3}$$

Where $\Delta_i's$ are difference operators, $\theta'_i s$ are error correction estimates, and $\varphi'_i s$ represent the long-run estimates. Furthermore, in this framework, the short-run estimates, intercepts, and adjustment speeds vary across sample, whereas, long-run estimates are similar for the panel (see, Eregha & Mesagan, 2020). Moreover, we use both the homogeneous and heterogeneous panel unit root tests (PURT), whereas the Friedman Cross-sectional Dependence (CD) test, Frees' test, Breusch-Pagan LM test of Pesaran & Chudik (2014), are employed to establish the existence of CD among the sample of countries. We then use the Pesaran CD test to determine the how appropriate is the 1st generation PURT. Also, we confirm cointegration

among the regressors using Westerlund (2007) by bootstrapping the critical values since CD exists. The variables used based on Andreoni & Levinson (2001), Stern (2004), Dasgupta et al. (2002), and Mesagan *et al.* (2018), include carbon emissions per person (CO_2), non-renewable energy use per capita (NEN) measured in kilowatts, renewable energy per person (REN) denoted in kilowatts, real GDP per head (Y), and capital investment (CI) proxied with fixed capital formation per GDP. Others include the interactions of non-renewable energy use and capital investment (NENCI), as well as that between renewable energy use and capital investment (RENCI). The last set of variables include trade openness (TO) and foreign direct investment (FDI) to the G20 nations. We extract data from 1990 to 2017 from the Global Carbon Atlas (2018), and World Bank's World Development Indicators (WDI, 2019).

4. Results And Discussion

4.1 Results

Table 2
Correlation of Variables

	REN	*CO_2*	*NEN*	*CI*	*Y*	*TO*	*FDI*
REN	1.0000						
CO_2	-0.5997	1.0000					
NEN	-0.5188	0.4861	1.0000				
CI	0.1158	-0.1081	-0.0285	1.0000			
Y	-0.4847	0.5891	0.1131	-0.1966	1.0000		
TO	-0.2615	0.2109	0.1763	0.0428	0.0602	1.0000	
FDI	-0.0126	0.0511	0.0253	0.0296	0.0746	0.1153	1.0000
Source: Authors' Compilation							

In Table 2, we present the correlation matrix to confirm the possibility of multicollinearity problem among the regressors. Despite that regression spuriousness is only caused by perfect collinearity, Table 2 still suggests evidence of a weak correlation, confirming the suitability of the estimated model.

Table 3
CD Test Results

Null Hypothesis: There is no CD among selected nations						
Tests	**I**		**II**		**III**	
	Statistic	**Prob.**	**Statistic**	**Prob.**	**Statistic**	**Prob.**
Breusch-Pagan LM test	1535.404	0.0000***	1498.577	0.0000***	1442.965	0.0067***
Pesaran CD test	2.607	0.0091***	2.066	0.0388**	1.577	0.1147
Friedman test	39.862	0.0022***	30.894	0.0296**	29.442	0.0432**
Frees test	4.727***		4.561***		4.404***	
Frees' Q distribution	0.0924	10%	0.0924	10%	0.0924	10%
	0.1204	5%	0.1204	5%	0.1204	5%
	0.1726	1%	0.1726	1%	0.1726	1%
***, ** Indicate 1%, 5% Critical Levels						

The CD tests make it possible to ascertain if the panel data exhibit cross-sectional dependence (CD) among them. CD in panel data is caused by common shocks and unexplained elements that are fused into the residual terms. As explained in the methodology section, we also use the CD tests to check the appropriateness of the first-generation panel stationarity tests. They include the Breusch-Pagan Langrage Multiplier (LM), the Pesaran CD, the Friedman chi-square, and the Frees normality test. Table 3 shows that we can reject the hypothesis of no CD in the panel data since the Friedman, Pesaran, and Breusch-Pagan tests are all significant at 1%. This is also confirmed by the Frees statistic of 4.727, 4.561, and 4.404 for Models I-III, which exceeds all the Frees' Q distribution critical values at 1%, 5%, and 10%. It implies that the Frees test is also significant at 1%. Even in Model III, where only the Pesaran CD is insignificant, we still strongly confirm CD. The implication is that we confirm existence of strong CD among the G20 countries because majority of the measures reject the main hypothesis. Hence, the use of 1st generation PURT is inadequate. We then present the 2nd generation PURT test, which accounts for CD (Pesaran, 2007). The Pesaran (2007) test is robust for CD by cross-sectionally augmenting the IPS statistic of Im, Pesaran, & Shin (2003). Next is to compare the cross-sectionally augmented IPS (CIPS) statistic with the cross-sectionally augmented Dickey-Fuller distribution (CADF) critical values at various levels.

Table 4
1st Generation PURT

Variables	Similar Unit Root Processes				Varied Unit Root Processes			
	@ Levels		@ First Differences		@ Levels		@ First Differences	
	Levin et al. (2002)	Breitung (2001)	Levin et al. (2002)	Breitung (2001)	Im et al. (2003)	ADF−Fisher	Im et al. (2003)	ADF−Fisher
REN	-2.8002	5.5726	-16.642***	-9.8403***	-0.9002	34.386	-4.9099***	419.609***
CO$_2$	-2.4754	4.6722	-10.009***	-4.5689***	-1.0235	49.305	-4.8823***	414.186***
NEN	-5.1175***	3.8829	-15.798***	-10.829***	-1.3668	36.262	-5.2705***	480.252***
CI	-8.9004***	-0.2750	-16.287***	-6.7620***	-2.0285**	72.254**	-4.2840***	307.880***
Y	-0.8709	10.2652	-10.221***	-3.8031***	0.5595	8.8073	-3.8757***	264.758***
TO	-6.6535**	0.1091	-21.287***	-12.972***	-1.6483	48.379	-5.1928***	457.387***
FDI	-10.719***	-5.6502***	-19.873***	−14.985***	-2.9402***	147.389***	-6.1364***	633.439***
RENCI	-2.7963	2.4965	-17.255***	-8.1856***	-1.0650	40.920	-4.6872***	368.067***
NENCI	-8.6538***	0.4703	-16.042***	-6.6518***	-1.9306**	66.138***	-4.2645***	305.148***
Note. **, *** mean 5%, 1% critical levels								

Table 4 displays the 1st generation panel unit test from the homogeneous and heterogeneous processes. Table 4 suggests that considering the homogeneous tests with Breitung (2001) and Levin et al. (2002), only foreign direct investment is stationary at levels, while every other independent variable is not stationary. Similarly, using the heterogeneous tests with ADF Fisher together with Im et al. (2003), only capital investment, FDI, and NENCI are stationary at levels, while renewable energy, NEN, CO$_2$, income, TO, and renewable energy-capital investment interaction term are not stationary at levels. Nevertheless, when the panel data are first differenced, all the variables became stationary. So, testing at 5% and 1% significance levels, the null hypothesis of unit root is rejected and we confirm stationarity of all the variables among the G20 nations. Then, 2nd generation PURT result based on Pesaran (2007) is presented in Table 5.

Table 5
2nd Generation PURT based on Pesaran (2007)

Regressors	CIPS Statistic @ Level	CIPS Statistic @ 1st difference	CADF Critical Values			Stationarity Decision
			10%	5%	1%	
REN	-1.761	-4.815***	-2.11	-2.2	-2.38	1st Difference
CO_2	-1.467	-4.535***	-2.11	-2.2	-2.38	1st Difference
NEN	-1.863	-4.881***	-2.11	-2.2	-2.38	1st Difference
CI	-2.330**	-4.255***	-2.11	-2.2	-2.38	Level
Y	-1.210	-3.365***	-2.11	-2.2	-2.38	1st Difference
TO	-2.028	-4.412***	-2.11	-2.2	-2.38	1st Difference
FDI	-3.336***	-5.583***	-2.11	-2.2	-2.38	Level
RENCI	-1.123	-4.621***	-2.11	-2.2	-2.38	1st Difference
NENCI	-2.417***	-4.266***	-2.11	-2.2	-2.38	Level
Note. *** and ** indicate 1% and 5% level of significance						

Evidence in Table 5 shows that capital investment, foreign direct investment, and non-renewable energy-capital investment interaction term are stationary at levels, while renewable energy, CO_2, NEN, income per capita, trade, and the renewable energy-capital investment interaction term are stationary when first differenced. Therefore, testing at 5% and 1% levels, the hypothesis of homogeneous unit root is rejected while stationarity is confirmed all variables among the G20 nations.

Table 6
Panel Cointegration Test based on Westerlund (2007) with Bootstrap

Hypothesis: There is no existence of cointegration		Model I		
Statistic	Value	Z-value	Probability	Robust Probability
Gt***	-2.303	-0.447	0.328	0.000
Ga***	-6.880	2.750	0.997	0.000
Pt***	-8.777	-0.471	0.319	0.000
Pa***	-6.392	0.899	0.816	0.000
Model II				
Gt***	-2.445	-0.081	0.468	0.000
Ga***	-5.604	4.313	1.000	0.000
Pt***	-12.689	-2.869	0.002	0.000
Pa***	-10.084	-0.038	0.485	0.000
Model III				
Gt***	-1.939	1.112	0.867	0.000
Ga***	-5.067	3.779	1.000	0.000
Pt***	-13.916	-4.677	0.000	0.000
Pa***	-10.341	-1.266	0.103	0.000
Note. *** indicates 1% critical level.				

We use Table 6 to present the Westerlund (2007) panel cointegration test, which provides an appropriate measure of long-run relationships in heterogeneous panels. Hence, as specified in Table 6, we conduct the cointegration test by bootstrapping the critical values since there is cross-sectional dependence. The optimal lag lengths and leads are chosen with the Akaike information criterion (AIC). Therefore, results in Table 6 implies that we reject null hypothesis of no cointegration at 1%. This confirms that there is long-run association among the regressors.

Table 7
Baseline Estimates for G20, lag length chosen based on AIC (max lag = 1)

Explanatory Variables	Explained Variable: ΔCO_2	Model I: ARDL (1,1,1,1,1,1,1)	
		Model II: ARDL (1,1,1,1,1,1,1,1)	
		Model III: ARDL (1,1,1,1,1,1,1)	
	I	II	III
A. **Short-run Panel Results**			
ECT	-0.06160* (0.03532)	-0.15312*** (0.05479)	-0.09392** (0.0459)
ΔY	0.00014 (0.00046)	-0.00012 (0.00072)	0.00030 (0.00027)
ΔY^2	-4.79342 (3.06980)	-2.14787 (3.41107)	-3.70155 (2.91370)
ΔREN	-0.74144 (0.67251)	-1.08328 (1.03392)	-
ΔNEN	0.23260 (0.14983)	0.26906 (0.18002)	-
ΔCI	-	-0.02997 (0.01975)	-
$\Delta RENCI$	-	-	-0.05080 (0.04484)
$\Delta NENCI$	-	-	0.00072** (0.00034)
ΔFDI	-0.00524 (0.01326)	0.00155 (0.00933)	-0.00398 (0.01043)
ΔTO	0.00777 (0.00678)	0.00765 (0.00728)	0.00557 (0.00721)
Constant	0.55216* (0.30516)	2.88186*** (0.99280)	1.18047** (0.52268)
Note: *Parentheses display the standard error; *, **, *** means 10%, 5%, 1% critical level.*			

We present the empirical results in Table 7 and Table 8. The panel short-run result is shown in Table 7, while we use Table 8 to display the long-run panel results. Three models are presented using the PMG. 'Model I' is estimated without the interaction terms and capital investment and 'Model II' is presented by controlling for capital investment but without the interaction terms. In 'Model III', we estimate only the interaction terms and control variables while excluding REN, NEN, and capital investment. This helps to remove the possible effect of multicollinearity between *RENCI, CI*, and *REN*, as well as, between *NENCI, CI*, and *NEN*. Also, the stepwise regression makes it possible to ascertain the crucial role of investment in the pollution abatement model in G20. The short-run result presented in Table 7 show that renewable energy use negatively impacts carbon emissions while keeping constant all the other explanatory variables in Model I and Model II. This suggests that renewable energy lowers the amount of pollution in G20. For non-renewable energy, evidence in Table 7 shows that it positively affects pollutions. Implication is that when keeping constant all the other variables, consumption of non-renewable energies enhances short-term emissions in G20. Considering capital investment, Table 7 shows that capital investment negatively impacts CO_2 emissions. It thus means that increases in capital investment can bring about a short-run decrease to CO_2 emissions in G20 nations. Regarding the interaction terms, evidence suggests that renewable energy and capital investment interaction negatively impacts short-run emissions, while it is positive for non-renewable energy and capital investment interaction. What is exciting in Table 7 is that both non-renewable energy and capital investment exerts a significant short-run positive impact on pollution at 5%. This is unlike the insignificant short-run impact that characterises each of the other major explanatory variables in Models I-III. Concerning the error correction terms (ECT), the ECT of Model I, Model II, and Model III are significantly negative every critical level. This corroborates the earlier long-run nexus confirmed by Westerlund (2007) cointegration test. It also means that the models are well specified since there is convergence towards long-run as short-term misalignments are corrected at the long run.

Table 8
Baseline Estimates for G20, lag length chosen based on AIC (max lag = 1)

Explanatory Variables	Explained Variable: ΔCO_2	Model I: ARDL (1,1,1,1,1,1,1)
		Model II: ARDL (1,1,1,1,1,1,1,1)
		Model III: ARDL (1,1,1,1,1,1,1)
	I	II	III
B. Long-run Panel Results			
Y	0.00063*** (0.00010)	0.00019*** (0.00002)	0.00039*** (0.00005)
Y^2	-1.51997*** (0.34945)	-0.46370*** (0.17760)	-0.47086*** (0.14467)
REN	-0.23567*** (0.04133)	-0.20850*** (0.02441)	-
NEN	0.30637*** (0.08751)	-0.05679** (0.02441)	-
CI	-	0.09153*** (0.01312)	-
RENCI	-	-	-0.00514*** (0.00047)
NENCI	-	-	0.00164*** (0.00012)
FDI	0.10687*** (0.03960)	-0.06066** (0.02425)	0.15927*** (0.03096)
TO	-0.03308*** (0.00917)	-0.00962** (0.00457)	-0.01162** (0.00453)

Note: *Parentheses display the standard error; *, **, *** means 10%, 5%, 1% critical level.*

Long-run estimates in Table 8 show that in both Models I and II, renewable energy negatively and significantly impacts carbon emissions while keeping constant all the other explanatory variables. This means that short- and long-run emissions are lowered by renewable energy in G20. Also, non-renewable energy positively and significantly impacts CO_2 emissions in Model I (i.e. without the inclusion of capital investment). However, when capital investment is controlled for in Model II, consumption of non-renewable energy negatively and significantly impacts G20 emissions. Meanwhile, capital investment itself exerts a positive and considerable impact on long-run emissions. Therefore, while capital investment might have been found to increase long-run emissions, its presence in the model has helped to reverse the positive impact of non-renewable energy use. Regarding the interaction terms, the long-run findings suggests that renewable energy and capital investment interaction exert a negative and significant effect on pollution. Meanwhile, non-renewable energy and capital investment interaction positively and significantly correlate with pollution. Interestingly, unlike the short-run results, all major variables significantly drive long-run carbon pollution at 5% and 1% significance levels. Economic implications and intuitions of these findings are discussed next.

4.2 Discussion of Findings

This empirical result has several economic intuitions. Firstly, the fact that renewable energy reduces both long- and short-run emissions means that consumption of renewable energy does not increase pollution among G20 economies. This result is in tune with the OECD result of Shafiei & Salim (2014) and the Chinese result of Chen et al. (2019). Moreover, the result is in sync with Bento & Moutinho (2016) for Italy and Dogan & Seker (2016) for top renewable energy nations. Again, since non-renewable energies worsened short- and long-run pollutions when estimated without capital investment, it is the main pollution concern among G20 nations. It thus corroborates earlier results of Shafiei & Salim (2014), Bento & Moutinho (2016), Dogan & Seker (2016), and Chen et al. (2019). Moreover, since capital investment exerts a short-run negative effect on CO_2 emissions means that investment technologies used in G20 nations can provide the needed impetus to reduce CO_2 emissions. It can also help the G20 nations to meet their short-run target set for 2020. It also means that to achieve their 2020 and 2030 goals, they can jointly leverage the use of environmentally friendly machines to reduce carbon emissions. The capital investment result is in tune with Mesagan, Isola, & Ajide (2019) for BRICS.

Moreover, the fact that the inclusion of capital investment reversed the earlier effect of non-renewable energy on long-run emissions is very striking. The intuition is that capital investment is crucial for reducing the long-run fossil fuel impact on pollutions in G20 nations. It also means that if G20 countries can focus on using only clean technologies for production, non-renewable energy consumption will become a tool to reduce pollution instead of increasing it. Besides, since findings show that energy from non-renewable sources positively impacts emissions of CO_2, its proportion in the overall energy mix must be reduced to abate the G20 pollution. Also, since capital investment interacts with renewable energy to lower long- and short-run pollution, it is crucial in the model. It implies that if energy consumption is to work through the capital investment channel to lower pollution in the G20, the share of renewable energies must increase compared to the non-renewable ones in their energy mix. This is because reducing pollution by augmenting non-renewable energy use with capital investment is not an option for G20 nations, without first reducing fossil fuel energy use significantly. It thus means that fossil fuel energies are the main pollution drivers in the G20, which can be remedied by augmenting it with clean technologies to fast-track global pollution reductions.

5. Conclusion

The paper analysed the impact of energy use in pollution reduction through capital investment channel in G20 economies. The study which covered the period of 1990 to 2017 employed the dynamic heterogeneous panel analysis via the pooled mean group. The study deviated from previous panel studies without consideration for cross-sectional dependence, even though the countries are heterogenous and are cross-sectionally dependent. Also, we disaggregated energy consumption into non-renewable and renewable to improve the literature. Hence, we estimated the models with and without augmenting energy consumption with capital investment and findings showed that for short-run and long-run, renewable energy lowered CO_2 pollution, while non-renewable energy increased emissions. Meanwhile, capital investment reduced short-run pollution, but with a long-run contrary result. Lastly, investment augmented renewable energy to lower both long- and short-run pollutions but provided worsening effect when augmented with non-renewable energy. To this end, the conclusion is that capital investment provides the crucial channel to reduce pollution in the G20. Given these findings, we suggest that if energy consumption is to work through the capital investment channel to lower pollution in the G20, the share of renewable energies must increase significantly. G20 countries should also focus on using only clean technologies for production as this will help in augmenting non-renewable energy use to reduce pollution level. Since some of them are already thinking in that realm, it should be sustained. However, for a few of them, the use of renewable energy is still very low as presented in Table 1. Therefore, various national governments in G20 must collaborate with private investors to encourage considerable investments in solar, wind, and other sources of renewable energies. This will help to significantly reduce global emissions below the 2^0C and a further 1.5^0C target.

Declarations

Ethics approval and consent to participate:

Not Applicable

Consent for publication:

Not Applicable

Availability of data and materials:

The data used in this study are available from the corresponding author on reasonable request

Competing interests:

The authors declare that they have no competing interests

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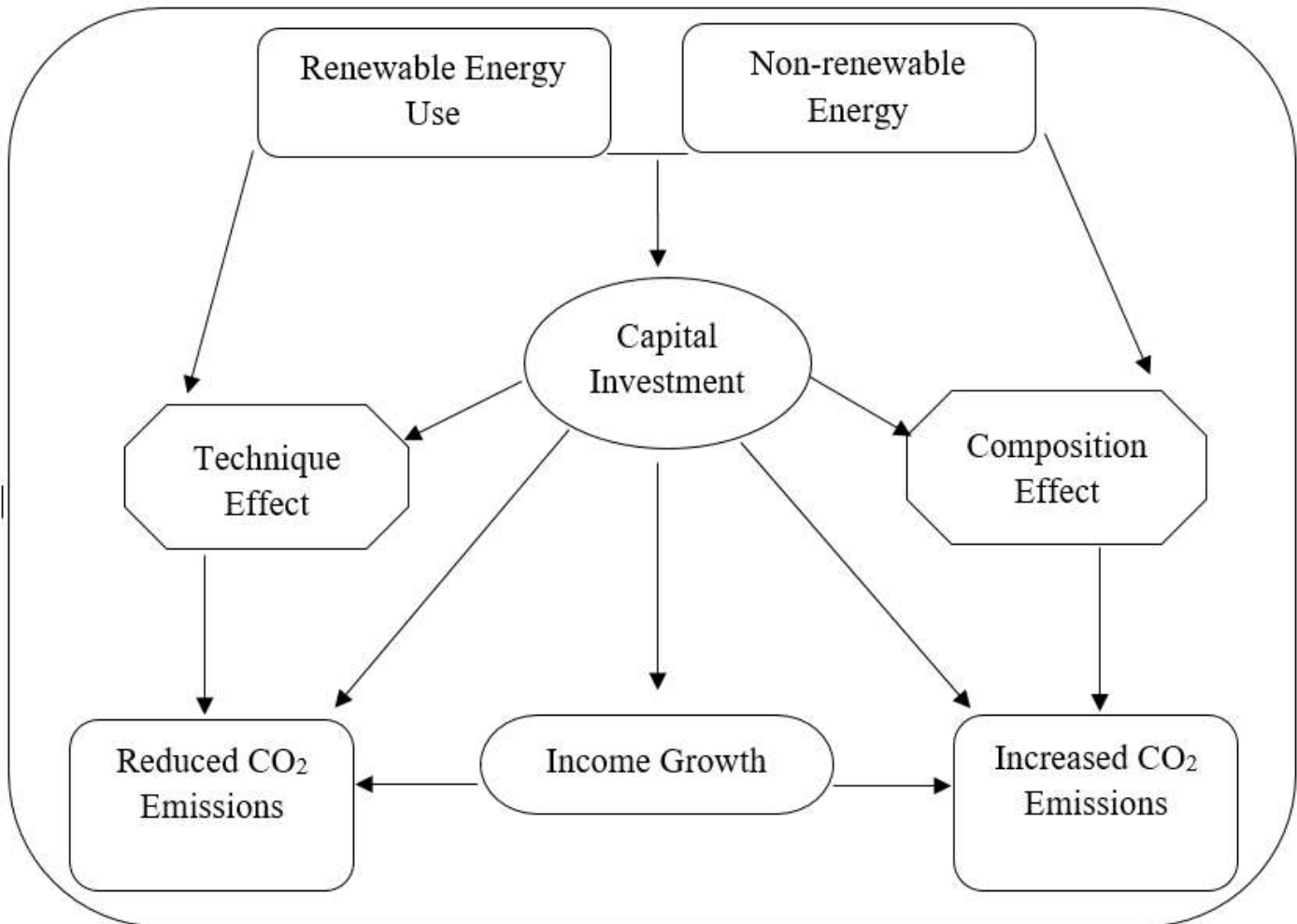
Figures

Figure 1

The Role of Capital Investment Pathway in Environmental Quality Source: Authors' Computation