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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

Environmental sustainability and climatic change mitigation seem central in the fight against global warming and continuous human sustenance in the 21st century. However, non-renewable and renewable consumption energies lie at the core of these pollution concerns, particularly among the G20 economies that are top pollution emitters in the world. Unlike other mediators in energy-pollution nexus, capital investment has been argued to ameliorate or amplify the relationship. To this end, the study specifically sets out to unravel the mediating role of capital investment in energy-pollution link together with other pollution confounders including trade openness, foreign direct investment and energy use for G20 economies over the period 1990-2017. Using the pooled mean group estimator, the study accounts for both cross-sectional dependence and heterogeneity among the countries. They key findings show that renewable energy to negatively impact carbon emissions in both the short- and long-run, while non-renewable energy positively having a reverse impact. In addition, the results show that capital investment as lowering pollution in the short-run but increases it in the long-run. Lastly, on interacting capital investment with renewable energy, pollution is found to reduce to pollution in both short- and long-run, while its interaction with non-renewable energy expands pollution in both short- and long-run. On the policy front, since capital investment provides an important channel to reduce pollution in G20 nations, it is therefore recommended 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.

Keywords: Capital Investment; Renewable Energy; Non-renewable Energy; Carbon Emissions.

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

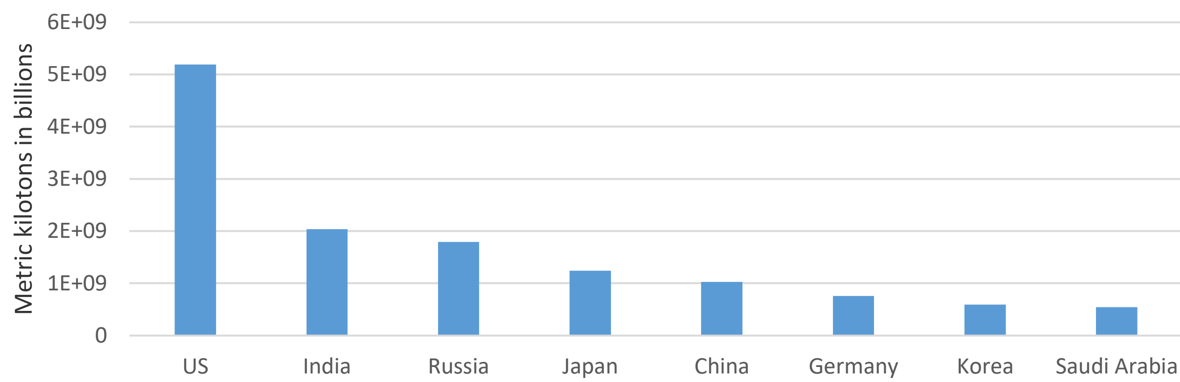
1. Introduction

The rising concerns about environmental sustainability and climate change necessitate the call by the UNFCCC[1] for countries to curb global warming. The Paris Agreement and other climatic agreements chart a new direction for nations to keep warming below 2, preferably to 1.5 Celsius, compared to pre-industrial levels. Climate change poses an enormous threat to ecosystems, with consequent adverse implications for human livability (Kerr, 2007; Yao *et al.*, 2015). The problems involving climate change and environmental pollution often emanate from human consumption of fossil fuels which emit large amount of carbon emissions. Hence, the environmental consequences of human activities 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 till now (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. Unarguably, most of the GHGs emissions generated globally are attributable to the activities of the G20 economies. Corroborating the preceding claim is Yao *et al.* (2015), affirming 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 largely rely on non-renewable energy with 77% of global energy use, and accounted for 82% of the world energy-related CO_2 emissions (IEA, 2018).

[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.

The G20[2] economies, comprising the European Union, twelve emerging nations, and seven developed countries, are notable for high levels of output growth. The huge success records of these set of countries in growth process can arguably be attributed to their massive capital investments, thus foisting on these countries highly industrialised nations. For instance, the United States (US), Germany, Canada, Australia, and Saudi Arabia are heavily industrialised while at the same time contribute significantly to global emissions. In 2016, the US is credited with the largest amount of CO_2 emissions, followed by India, Russia, and Japan, China, Germany, Korea, and Saudi Arabia in that order (see Fig. 1).

Fig 1: Trend of Carbon Emissions across the major carbon emitters in 2016



Source: Graphed from the underlying data source (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). Given the fact that energy use causes GHGs emissions (see, Inglesi-Lotz & Dogan, 2018; Dogan & Seker, 2016; Mesagan *et al*, 2019), and capital investments can both mitigate or amplify environmental pollution substances (see, Blomquist and Cave, 2008; Tang & Tan, 2015; Mesagan, 2015; Zhang

[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).

and Zhou 2016; Haider *et al.* 2019), thus informing the focus on the G20 nations which are inherently endowed with these two elements.

Given the foregoing, this study's motivations are drawn by the following considerations. First, there has been various commitments since 2009 to end government support for fossil fuels and make "finance flows consistent with a pathway toward low greenhouse gas emissions and climate-resilient development" (Paris Agreement, Article 2.1c), yet G20 governments continued to provide significant support to fossil fuels. For instance, International Institute for Sustainable Development (IISD, 2020) report, states that the G20 governments provided $584 billion annually through direct budgetary transfers and tax expenditure, public finance, price support, and state owned enterprise investment for the production and consumption of fossil fuels at home and abroad. In particular, the governments of each of these countries, have been argued to provide more support to oil and gas production than any other stage of fossil fuel-related activity, at $277 billion (47% of the total support to fossil fuels). The situation seems more severe during the COVID-19 outbreak when the G20 countries allocated some $170 billion in public money commitments to fossil fuel-intensive.

Second, the G20 economies host 80% of the world total installed renewable power generation capacity, and hold 75% of total global deployment potential of all renewables in the energy sector for the period from 2010 to 2030, as estimated by International Renewable Energy Agency (IRENA).

Lastly, capital investments have been argued to constitute about one-quarter of gross global product in monetary terms, thus causing about 30 percent of global greenhouse gas emissions (Sodersten et al. 2017). Not only that, the entire process of capital investments causes anthropogenic greenhouse gas emissions. These emissions occur at different stages: during the construction phase, in the use phase, and in the end-of life-phase ((see Muller et al. 2013) for detailed exposition).

Undoubtedly, an extensive empirical literature exists on energy-pollution nexus but is largely 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 increasing impacts of non-renewable energy consumption on pollution level. Regarding the channels of pollution transmissions, studies such as Pata (2018), Mesagan & Nwachukwu (2018), Khan *et al.* (2018), Baloch *et al.* (2019), Sharif *et al.* (2019), and Charfeddine & Kahia (2019) identified financial development routes. Whereas studies such as 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 such as urbanisation, trade, and population growth. Specifically, both Frankel & Rose (2005), and Li *et al* (2015) attributed trade impact of environmental pollution to polity channel, while Shafiei & Salim (2014), Inglesi-Lotz & Dogan (2018), Chen *et al.* (2019), and Sharif *et al.* (2019) provided pollution reducing impact of renewable energy channel in the pollution abatement model.

In the light of the foregoing, it is apparent that the debate surrounding energy-pollution nexus is ongoing and inconclusive. The need to re-investigate the nexus for G20 economies via the capital investment channel is salient for these set of countries as identified in the literature (See, Sims, Rogner & Gregor, 2003; Tang & Tan, 2015; Mesagan, Akinsola, Akinsola & Emmanuel, 2022). This is so as capital investment can offset the threats of CO_2 emissions through the technique effect it creates and can equally amplifies it through its embodied carbon content. However, it has received less attention from previous related studies, especially those focusing on G20 nations[3] that have a massive amount of industrial productivity and carbon pollution. Thus, this paper addresses the energy-pollution problem via the capital investment channel. Examining such relationship for the G20 economies cannot be overlooked as they are faced with fulfilling their bargain of the Paris Agreement without lowering their productivity amid the persistent increase in CO_2 emissions. Consequently, the main objective is to analyse the role of energy in CO_2 pollution via the capital investment channel in the G20. Specifically, the study

[3] With the exception of Ajide and Ibrahim (2021) that investigated the threshold effects of capital investments on carbon emissions in G20 economies.

examines the effect of non-renewable and renewable energy use on environmental pollution. It examines the impact of capital investment on pollution, and then analyses the impact of both energy sources on pollution through the capital investment channel. This study extends the frontiers of knowledge in four ways. Firstly, the study disaggregates the sources of energy into renewable and non-renewable resources in order to identify the main cause of pollution in G20 economies 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.

The balance of the paper is as follows: section 2 presents the facts on alternative energy usage and carbon pollution in G20; section three dwells on the research methodology; section four discusses the result, and section five concludes with policy implications.

2. Facts on Alternative Energy Use and Carbon Pollution in G20 Economies

2.1 Carbon Emission and Energy Usage by Types of Fuel

In Table 1, we present the relationship between energy consumption by fuel types and CO_2 emissions in G20 economies. For most countries within the G20, available evidence shows a direct and positive link 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 shown 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 consumption of renewable energy to 36.8% and was able to lower its CO_2 emissions to 458 MT from 491.3 MT in 2015. The increase in the production of biofuels on a large scale enables Brazil to achieve 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 correspondingly reduced to 1490 MT from the initial 1521.9 MT. Both China and the United Kingdom marginally increased their renewable energy consumption from 11.8% to 13.0% and from 18.2% to 18.6%, respectively. Both countries were able to reduce their CO_2 emissions from 9164 MT to 9123 MT, and from 433.4 MT to 406.4 MT between 2015 and 2016 respectively. Similarly, Italy increased its fossil energy use marginally from 83.5% to

84.0% between 2015 and 2016, and its CO_2 emissions rose marginally from 336.2 MT to 336.9 MT. Unlike others, the increase in renewable energy use from 7.8% to 9.2% by Japan, led to significant drop in carbon emissions from 1206.6 MT to 1191.2 MT over the same period.

For France, substantial amount of energy is generated from renewable sources. However, as depicted in Table 1, attempts at increasing fossil fuel energy from 50.3% to 52.1% causes CO_2 emissions to significantly increase 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% during the same period. The CO_2 emissions were reduced for other G20 economies as they reduce their fossil fuel energy consumption. These countries 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 period of two years. Moreover, other G20 economies that witnessed one-to-one increase in both non-renewable energy and CO_2 emissions are 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 increase in their CO_2 emissions.

2.2 The Link between Fossil Fuel Energy Use and Environmental Quality

The framework presented in Figure 2 depicts the mediating role of capital investment in CO_2 emissions for the G20 nations. Figure 2 graphically depicts how renewable and non-renewable energy use can be used to curtail and increase the volumes of carbon emissions among the G20 countries. From the figure, the amount of renewable and non-renewable energies in the energy mix, will likely alter the situation of CO_2 emissions in G20 economies. 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).

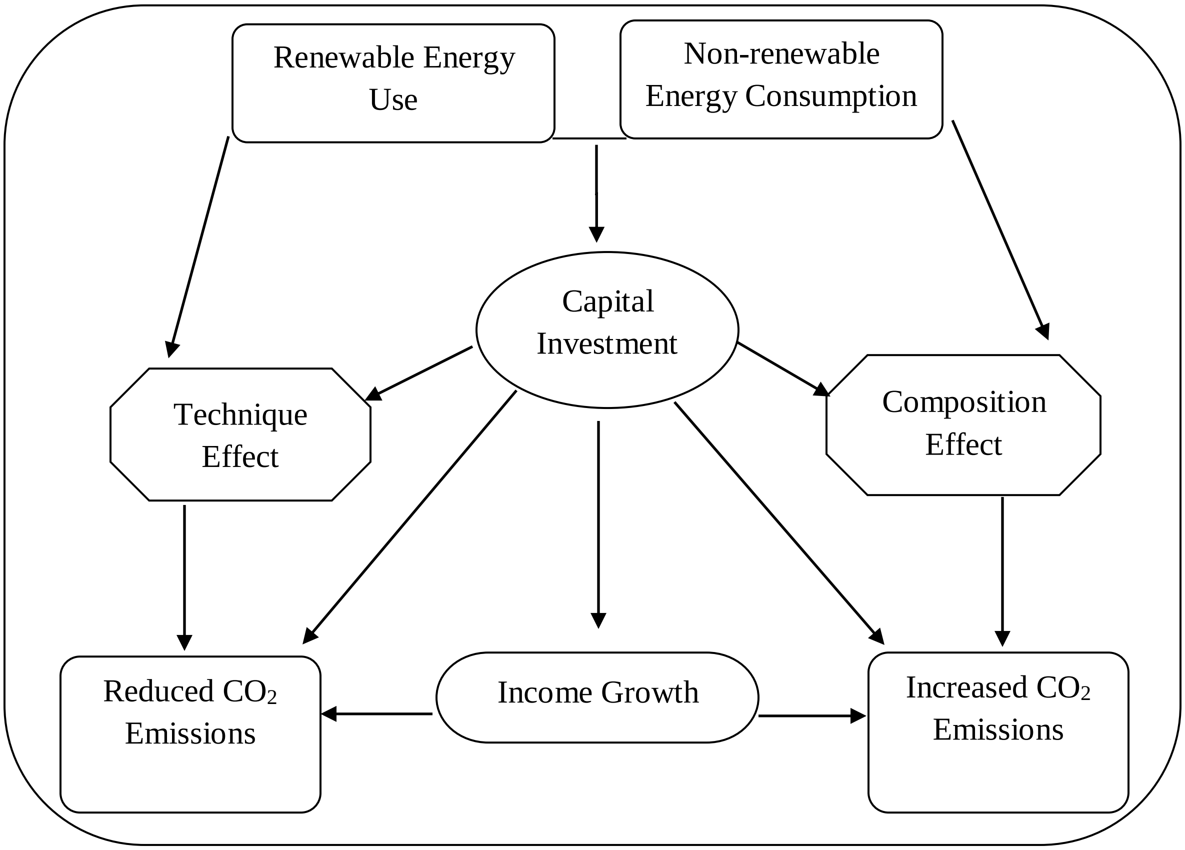


Figure 2: The Role of Capital Investment in Environmental Quality
Source: Authors' Computation

Contrariwise, 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. 2 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, and 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. 2. 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 would also increase. Therefore, for G20 economies to lessen CO_2 emissions 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, Climate Action Tracker (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.

Similarly, 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 increase in foreign exchange earnings due to the increase in world crude oil price of the early 2000s. It is one of 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 sets 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 employs 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, trade openness and foreign direct investment while accounting for capital investment as a mediating variable. Thus, we specify the model as follows:

$$C0_2 = f(Y, Y^2, REN, NEN, CI, FDI, TO) \quad (1)$$

Where $C0_2$ is carbon emission per capita; Y is the per capita gross domestic product; Y^2 is square of GDP per capita; REN is renewable energy consumption; NEN is non-renewable energy consumption; CI is capital investment; FDI is foreign direct investment and TO stands for trade openness respectively.

To express equation (1) in an empirical estimation form, this takes the following form

$$C0_2 = \alpha_0 + \alpha Y + \alpha Y^2 + \alpha REN + \alpha NEN + \alpha CI + \alpha FDI + \alpha TO + \varepsilon \quad (2)$$

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 make the technique effect to neutralise the threats of CO_2 emissions as suggested by 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 equation (1):

$$a_i(L)y_{it} = b_i(L)x_{it} + d_i z_{it} + e_{it} \quad (3)$$

For country i , where $i = 1, .., N$. Its 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 $i = 1,2, \ldots N$, and period $t = 1,2, \ldots T$ for the dependent variable y becomes:

$$y_{it} = \sum_{j=1}^{q} \omega_{ij}\, y_{i,t-j} + \sum_{j=0}^{p} \gamma_{ij}'\, x_{i,t-j} + \mu_i + \varepsilon_{it} \qquad (4)$$

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

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

$$\Delta y_{it} = \theta_i\left(y_{i,t-1} - \varphi_i' x_{i,t-1}\right) + \sum_{j=1}^{q-1} \omega_{ij}\, \Delta y_{i,t-j} + \sum_{j=0}^{p-1} \gamma_{ij}'\, x_{i,t-j} + \mu_i + \varepsilon_{it} \qquad (5)$$

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 samples, 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 gross fixed capital formation to 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) of the G20 nations. We sourced data for the period spanning 1990-2017 from the Global Carbon Atlas (2018), and World Bank's World Development Indicators (WDI, 2019). For the empirical implementation of the foregoing models and data analyses, this study employs STATA 16 version owing to its flexibility and elegance.

4. Results and Discussion

4.1 Results

Table 2: Correlation of Variables

	REN	***CO₂***	***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. Given the fact that regression spuriousness is often caused by perfect collinearity among or between variables of interest, Table 2 evidently suggests a weak correlation, thus confirming the suitability of the estimated models.

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 the variables. 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% levels. 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

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 for 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.

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)
ΔY²	-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)	-
ΔRENCI	-	-	-0.05080 (0.04484)
ΔNENCI	-	-	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.*

Table 6 presents the Westerlund (2007) panel cointegration test, which provides an appropriate measure of long-run relationships in heterogeneous panels. The Table conducts a cointegration test by bootstrapping the critical values since there is cross-sectional dependence. The optimal lag lengths and leads are chosen using the Akaike information criterion (AIC). From the table, we reject the null hypothesis of no cointegration at 1%. This confirms that there is a long-run association among the regressors.

Tables 7 and 8 present the empirical results. The panel short-run result is shown in Table 7, while Table 8 displays 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,* on the one hand, and between *NENCI, CI,* and *NEN* on the other hand. Also, the stepwise regression makes it possible to ascertain the crucial role of capital investment in the pollution abatement model of the G20 economies. The short-run results in Table 7 show that renewable energy use negatively impacts carbon emissions while keeping constant all the other explanatory variables in Models I and II. This suggests that renewable energy lowers the amount of pollution in G20. For non-renewable energy, it is evidently clear in Table 7 that it positively affects pollutions. Implication is that while keeping all other variables constant, non-renewable energy consumption enhances short-term emissions in G20. Considering capital investment, Table 7 shows its negative impacts on CO_2 emissions. Suggesting an increase in capital investment brings about a short-run decrease in CO_2 emissions of the G20 nations. Regarding the interaction terms, evidence suggests that interacting renewable energy with capital investment negatively impacts short-run carbon emissions, while it is positive for the interaction between non-renewable energy and capital investment. Interestingly, Table 7 shows the interaction between non-renewable energy and capital investment exerting a significant short-run positive impact on pollution at 5%. This is unlike the insignificant short-run impacts that characterize each of the other major explanatory variables in Models I-III. Concerning the error correction terms (ECT), the ECTs of Model I, Model II, and Model III are significantly negative at critical levels. This corroborates the earlier long-run nexus confirmed by Westerlund (2007) cointegration test. It also means that the models are well specified as there is a convergence towards long-run path.

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)
Y²	-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 all the other explanatory variables constant. 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 suggest that the interaction between renewable energy and capital investment exerts 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

The empirical findings have several economic implications. Firstly, the fact that renewable energy reduces both long- and short-run emissions, suggesting that consumption of renewable energy does not increase pollution in G20 economies. This result is in tune with Shafiei & Salim (2014) and 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, thus implying that it remains the main pollution concern among the G20 nations. These findings corroborate the earlier results such as 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, suggesting that investment technologies in G20 nations can be used to reduce CO_2 emissions. It can also help the G20 nations to meet their short-run target 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 aligns with Mesagan, Isola, & Ajide (2019) for BRICS.

Moreover, the fact that the inclusion of capital investment reversed the negative 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 environmental impacts of fossil fuels among the G20 nations. It also means that if the 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 interacting capital investment with renewable energy reduces long- and short-run pollutions, thus suggesting its cruciality in the energy mix of the G20 economies. 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 covered the period straddling 1990-2017 using the dynamic heterogeneous panel analysis of the pooled mean group. This study deviated from previous panel studies by accounting for cross-sectional dependence, since the considered countries are heterogenous and are cross-sectionally dependent. The study equally disaggregated energy consumption into non-renewable and renewable in order to gain a better understanding of energy-pollution nexus. Hence, the models are estimated with and without augmenting energy consumption with capital investment. The findings showed renewable energy as lowering CO_2 emissions both in the short and long runs, while non-renewable energy increased carbon emissions. Meanwhile, capital investment reduced short-run pollution, but with a contrary result in the long run. Lastly, investment augmented with renewable energy exerts reducing impacts on pollutions both in the long- and short-runs, however amplifies pollution impacts when interacted with non-renewable energy. To this end, the study concludes that capital investment provides the crucial channel of reducing 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 reducing pollution level. However, the use of renewable energies seems limited for few of the countries within the G20 group as presented in Table 1. It is therefore suggested that various national governments in G20 economies should collaborate with private investors to encourage sustainable investments in solar, wind, and other sources of renewable energies. This will help to significantly reduce global emissions below the 2^0C and preferably 1.5^0C preindustrial levels.

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