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# A heterogeneous analysis of the nexus between energy consumption, economic growth and carbon emissions: Evidence from the Group of Twenty (G20) countries

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**Abstract**
The purpose of this study was to examine the nexus amid economic growth, energy consumption and carbon emissions in G20 countries for the period 1992 to 2014. In order to obtain valid and reliable outcomes, more robust econometric techniques were employed. From the results, the studied panel was heterogeneous and cross-sectionally dependent. Also, the series of observed variables were first-differenced stationary and co-integrated. The key findings from the CCEMG and the AMG regression estimators adopted showed that economic growth and energy consumption promoted the emission of carbon in the countries. In addition, urbanization and foreign direct investments as control variables escalated the rate of the countries' CO2 emissions. From the discoveries of the Dumitrescu and Hurlin panel causality test, a feedback causality between economic growth and CO2 emissions; energy consumption and CO2 emissions; and between urbanization and CO2 emissions were correspondingly unveiled. However, a one-way caual link was evidenced from foreign direct investments to CO2 emissions. This exploration is vital because it will propel the countries to formulate policies that could help them to minimize

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their dependence on environmentally unfriendly energy sources, while promoting the usage of clean energies like solar, wind, biogas, biomass and hydropower among others. The study is also pertinent because it will aid the countries to plan, organize and implement environmental policies in compliance to their macroeconomic objectives. When this is accomplished, energy conservation policies implemented to minimize the emanation of CO2 will improve the countries' economic growth.

**Keywords**

Economic growth, energy consumption, carbon emissions, G20 countries, CCEMG and AMG regression estimators

## Introduction

According to literature the usage of energy rises with an upsurge in economic activities. This surge in energy consumption leads to environmental deterioration through the emission of carbon. As cited in Mardani et al. (2018), the world economy will experience some tremendous growth by 2050. While the growth in leading economies are projected to rise, that in developing regions are expected to be higher, with an average of 3.6% in low-income countries, and 0.8% in high-income countries of which G20 nations are no exception. Similarly, global energy consumption is anticipated to rise by 80%, whilst greenhouse gas emanations are also projected to proliferate by 50% over the same period. The above projections are in tandem with that of Kahouli (2018), Nkengfack and Kaffo (2019) and Erdoğan et al. (2020), who postulated that countries that experience more economic development consume a lot of energy, and therefore causes more environmental degradation. The energy-growth-environment link has been widely studied with huge number of articles in recent years. The debate is still ongoing and G20 countries have been considered either at the country specific level, "developed" country terms or with a focus on renewable energy. For instance, Mardani et al. (2018) investigated the relationship between CO2 emissions, energy consumption and economic growth in G20 countries for the period 1962 to 2016. From the study's adaptive neuro-fuzzy inference system (ANFIS) model, energy consumption and economic growth significantly predicted the emanation of CO2 in the nations.

Xu, Zhong and Qiao (2020) also examined the nexus between economic growth, biofuel energy consumption and CO2 emissions in seven selected G20 countries over the period 2001 to 2017. From the results of the fully modified ordinary least squares regression estimator, the environmental Kuznets curve (EKC) was validated between economic growth and CO2 emissions. Also, biofuel energy consumption had a materially negative impact on the effusion of CO2 in the countries. Hsiao-Tien and Chun-Chih (2018) explored the affiliation between CO2 emissions, energy resources and economic growth in the G20 for the period 1991 to 2016. From the descriptive statistical analysis results, an absolute decoupling effect seemed to have occurred with a drop in environmental related pressure and the continuation of economic growth. The panel cointegration test results also affirmed a long-run equilibrium relationship between carbon emissions, fossil fuel, real GDP, and the different types of clean energies like renewable energy, hydropower and nuclear energy. The estimation results further validated the existence of the Carbon Kuznets Curve (CKC) hypothesis.

Additionally, the emanation of $CO_2$ was positively elastic to fossil fuel and negatively inelastic to renewable energy, hydro power and nuclear energy, although renewable energy's average per capita compound annual growth rate reached 14%. Finally, the panel vector error correction model revealed among others that, the use of nuclear energy was a key means for dealing with carbon emissions.

The above explorations though insightful, failed to consider the issue of cross-sectional dependence and slope heterogeneity in their analysis. This is very detrimental because according to Mensah et.(2020), Musah et al. (2020a), Li et al. (2020) and Musah et al. (2020b), the negligence of cross-sectional dependence and slope heterogeneity could lead to biased estimates and inferences. This study was therefore undertaken to help fill that void. All the nineteen (19) member countries of the G20 were used for the analysis because they are among the greatest emitters of carbon in the world (Erdoğan et al., 2020). As indicated in Mardani et al. (2018), the ratio of $CO_2$ emanations from G20 countries to overall $CO_2$ emittances was 91% in 1970, 88% in 1980, 86% in 1990 and 2000, 84% in 2010, and 83% in the year 2017. These high levels of emissions called for an investigation of this nature to be undertaken.

The novelties of this research are in threefold. Firstly, the econometric methods employed by this research are significantly different from prior investigations. For instance, the study used the Common Correlated Effects Mean Group (CCEMG) estimator of Pesaran (2006) and the Augmented Mean Group (AMG) estimator of Eberhardt and Teal (2010) and Eberhardt and Bond (2009) to explore the elastic effects of the explanatory variables on the explained variable. The idea of the CCEMG estimator is to approximate the projection space of unobserved common factors with the inclusion of cross-sectional averages of the variables in the regression equation. The AMG estimator on the other hand, follows an augmented process and does not treat unobserved common factors as nuisance as in the case of the CCEMG estimator. These estimators were engaged because they are robust to cross-sectional dependence, slope heterogeneity and exogenous or endogenous regressors. Studies like Yao and Tang (2020), Hsiao-Tien and Chun-Chih (2018), Mardani et al. (2018) and Xu, Zhong and Qiao (2020) among others, conducted on G20 countries failed to employ these robust second-generation econometric techniques.

Secondly, a lot of studies conducted on G20 countries failed to consider the issue of omitted variable bias (for instance, Mardani et al., 2018). This is disadvantageous because according to Clarke (2005), omitted variable bias could lead to unfair and inconsistent estimates. To avoid the above consequence, the study controlled for urbanization and foreign direct investments. Finally, prior investigations conducted on G20 countries failed to explore the direction of causalities amid series (for instance, Erdoğan et al., 2020). However, according to Mensah et al. (2019) and Li et al. (2020), the affirmation of long-run equilibrium connections between variables implies, there might be some degree of causations amongst them. To help bridge the above gap, the study engaged the services of the Dumitrescu and Hurlin (2012) panel causality test (henceforth D-H causality test) which is resilient to cross-sectional correlations and slope heterogeneity, as evidenced in this exploration.

This research is relevant because it proposes measures to help improve environmental quality in the studied countries. The investigation is also significant, as it adds to the already existing literature on the connection amid economic growth, energy consumption and $CO_2$ emanations. The other sections of the research are grouped as follows; part two presents literature that support the topic understudy, whilst part three describes materials and procedures that directed the conduct of the analysis. The fourth section reports the study's empirical findings, whilst discussions of the results are addressed in the fifth section. Conclusions and policy recommendations are finally outlined in the sixth section.

## Literature review

This aspect of the study reviews literature that support the topic understudy. The reviews are segregated into the energy-growth-emission link at the developed country level and the energy-growth-emission link at the developing country level.

### *Energy-Growth-Emission link at the developed country level*

At the developed country level, Işık et al. (2019) tested the EKC hypothesis for ten US states having the highest levels of carbon dioxide emissions. The study employed panel estimation methods robust to cross-sectional dependence in its analysis. From the empirical findings, the EKC (inverted U-shaped) hypothesis was valid only for Florida, Illinois, Michigan, New York, and Ohio. Interestingly, the negative impacts of fossil energy consumption on CO2 emissions in Texas was not detected statistically, although that state is the leading oil-producing state in the country. Furthermore, the positive impacts of renewable energy consumption on Florida was considerably low when compared to the other states. Even though the study was conducted on states in the same country, the discoveries were conflicting. These contrasting outcomes indicate that the energy-growth-emission debate is unceasing and warranted for an exploration like ours.

Mahmood et al. (2020) investigated the environmental effects of economic growth and energy consumption in Saudi Arabia for the period 1968 to 2014. From the findings, economic growth and energy consumption contributed to high CO2 emissions in both the long-run and the short-run. This means, increasing economic growth and the consumption of energy in the Kingdom had social costs on the economy in terms of pollution. This discovery is very insightful; however, it should be interpreted with caution because the study was confined to only Saudi Arabia. The results might be different if other countries were included in the analysis. Our research was therefore worthwhile since it could unravel outcomes that could support or rebut that of the above.

Waheed et al. (2019) surveyed both single country and multi-country studies that investigated the association between economic growth, energy consumption and carbon emissions. The focus of the survey was on the coverage of countries, modeling methodologies, study periods as well as empirical conclusions. From the disclosures, carbon emission was not linked with economic growth in developed countries. Also, higher energy consumption was found to be a major culprit of high carbon emissions in developed nations. These outcomes are very essential to the academic community; however, they must be interpreted with caution because not all developed nations in the world were considered in the analysis. Also, there might be other modeling methodologies that the studies did not take into consideration. If other different modeling methodologies and nations had been factored into the analysis, the outcomes might be different.

Balcilar et al. (2020) investigated the relationship between carbon dioxide emissions, energy consumption and economic growth in G-7 countries from a historical perspective. Taking time-varying interaction and business cycle into account, the study adopted the historical decomposition method in its analysis. From the results, Canada, Italy, Japan and partly the USA needed to sacrifice economic growth if they aimed to reduce CO2 emissions by decreasing fossil-based energy usage. This situation was not valid since the early 1990s for France, throughout the analysis period for Germany and a few exceptions in all periods for the UK. Furthermore, empirical results provided evidence contrary to the EKC hypothesis for Canada, Germany, Japan, the UK and the USA. The study found BC-shaped and N-shaped curves for France and Italy, respectively. Although the EKC hypothesis was not valid for Germany and the UK, economic growth had no damaging effect on environmental quality. Also, this effect seemed to be cyclical for the USA. Although the investigation was undertaken on member countries of the G-7, the outcomes were contradictory. These conflicting outcomes underscored the conduct of our exploration.

Park and Hong (2013) examined the correlation between South Korea's economic growth, CO2 emissions and energy consumption for the period Q1 1991 to Q4 2011. The study employed regression technique for the relational analysis among the various overall indices, whilst the Markov switching model was engaged for the detailed analysis. From the results, South Korea's economic growth and CO2 emission were coincidental. The correlational analysis also showed a significant affiliation between economic growth and fossil fuels, which emitted CO2, such as coal in the industrial sector, petroleum products in the industrial and transportation sectors, and liquefied natural gas in the residential/commercial and industrial sectors. These revelations are very relevant; however, the study was conducted on only South Korea which have different levels of economic growth, CO2 emission and energy consumption as compared to other nations. The investigation was also confined to a specific time frame (Q1 1991 to Q4 2011) even though other periods could have been considered. Therefore, the results cannot be generalized for all nations in the world because, if other countries and time frame were considered, the outcomes could be different.

### *Energy-Growth-Emission link at the developing country level*

At the developing country level, Awodumi and Adewuyi (2020) investigated the role of non-renewable energy in economic growth and carbon emissions among the top oil producing economies in Africa for the period 1980 to 2015. The study revealed an asymmetric effect of non-renewable energy consumption (petroleum and natural gas) on economic growth and carbon emission per capita in all the selected countries except Algeria. In Nigeria, although positive change in non-renewable energy consumption retarded growth, it reduced emissions. In the case of Gabon, increase in the consumption of these energy products promoted growth and enhanced environmental quality. Consumption of these energy types had negligible impact on environmental pollution in Egypt as it enhanced economic growth. While positive change in non-renewable energy consumption contributed to economic growth in Angola, the effect on carbon emission was mixed across time and energy type. In addition, the influence of negative change in petroleum and natural gas consumption is similar to those observed for positive change in Egypt and Nigeria. Though the same non-renewable energy proxies (petroleum and natural gas) were used for the analysis, the discoveries were conflicting across the various countries, collaborating that of Adewuyi and Awodumi (2017a) who indicated in their study that the energy-growth-emission linkages differ across countries even in the same region. These conflicting outcomes signposts that the energy-growth-emission argument is unceasing and demanded for an exploration of this nature.

O'Ryan et al. (2020) investigated the economy-wide impact of renewable energy expansion in Chile's energy mix, by employing the Computable General Equilibrium (CGE) model. From the discoveries, the Business as Usual (BAU) scenario, in which structural changes were not considered, significantly overstated expected emissions. On the other hand, when structural changes were considered in the model, Chile advanced towards its declared Nationally Determined Contribution (NDC) to reduce greenhouse gas emissions. This revelation is very essential; however, it must be interpreted with caution because the study was only confined to Chile. The outcome might therefore not be robust enough for the purpose of generalization. Also, the study was limited to only renewable energy. The result might not be same if non-renewable energy was considered in predicting the emanation of emissions in the country. Our study, though also limited to non-renewable energy, was deemed essential since it could unravel findings that could support or rebut the above discovery. Pata (2018) conducted a study in Turkey for the period 1974 to 2014. From the results, economic growth had a material connection with CO2 emissions. However, renewable energy consumption had no affiliation with the emission of carbon in the country. This discovery is very insightful; however, it must be interpreted with caution because the study was limited to only Turkey. The revelation might not be the same if other countries outside Turkey were considered in the analysis.

Adewuyi and Awodumi (2017b) also analyzed the relationship among biomass energy consumption, economic growth and carbon emissions in West Africa for the period 1980–2010. This connection was explored by integrating the pollution production function and energy demand function with an augmented endogenous growth model. Employing the three stage least squares (3SLS) regression estimator, a completely significant interactive relationship (feedback effects) amid GDP, biomass energy consumption and carbon emission in five West African countries (Nigeria, Burkina Faso, The Gambia, Mali and Togo) was established from the overall results. A partially significant linkage among the variables in the remaining West African countries was also unfolded. This exploration is vital; however, it was limited only to biomass energy consumption. Results of the study can therefore not be generalized for all sources of energy used in the countries and the rest of the world. Samour et al. (2019) tested the impact of banking sector development on Turkey's CO2 emissions. From the study's ARDL estimates, improvements in the Turkish banking sector development led to increased energy consumption, which subsequently caused high CO2 emissions in the country. Though this finding is very relevant, it should be interpreted with much care because, the exploration was confined to only the banking sector of Turkey. There is a possibility that, if the other sectors of the economy were included in the analysis, the results might be different. The outcome must further be interpreted with caution because the study was conducted at the firm level. The revelation might not be the same if the study had been conducted at the country level. Our exploration is different from the above because it investigated the linkage amid energy consumption, economic growth and CO2 effusions at the country level.

## Materials and methods

### *Theoretical rationale and model specification*

In order to comprehensively examine the nexus between economic growth, energy consumption and the emanation of carbon in G20 countries, a multivariate panel econometric model was proposed by incorporating urbanization and foreign direct investments as control variables to help reduce the issues of omitted variable bias. In the model, CO2 emissions was the explained variable, whilst economic growth and energy consumption were the main explanatory variables of concern. CO2 emission was employed as a response variable because it has been proven by Mensah et al. (2019), Jian et al. (2019) together with Karasoy and Akçay (2019) among others that, it is one of the best measures of environmental degradation. Also, as economic growth of countries increases, the life style of people also changes (shift in consumer behavior and needs). For instance, the use of automobiles, electronic items and other household appliances increases as the economic growth of nations upsurges. This shift in consumer behavior and needs not only influence the consumption of energy, but also affect the appeal for other energy consuming goods and services, that ultimately escalate the level of emissions in nations. Therefore, in line with the works of Mahmood et al. (2020), Antonakakis et al. (2017) and Nkengfack and Kaffo (2019), economic growth was introduced into the model as a determinant of CO2 emission. Additionally, activities like industrialization and expansion in businesses as a result of increase in population cannot be achieved without energy. The energy used to pursue the aforesaid activities are largely dominated by fossil fuels, natural gas, coal among others. These energy sources are not environmentally friendly. Notably, G-20 economies are richer in average and they emit the vast majority of the worlds' CO2 emissions. This is due to the reason being that countries within this panel use mostly oil (in other words consume oil more) as compared to coal, gas and other renewable energy sources-even though they host larger capacities of low-carbon electricity generation than other regions in the world combined. Statistically, G20 economies together, are responsible for three-quarters of global oil consumption. According to a report from Andrews (2016), G-20 countries obtain 41.5% of their total energy from electricity whereas the remaining 58.5% obtained from oil, is dominantly consumed in areas like transportation, industrial processes and heating among others. Based on the above assertions, the study considered oil as a proxy of energy consumption instead of gas, coal or renewable energy sources. Energy consumption was therefore introduced into the model as a determinant of CO2 emittance collaborating those of Ali et al. (2019), Saud et al. (2019) and Phong et al. (2018). In most G20 countries, a lot of people migrate to big cities in search for jobs, economic prosperity, developed infrastructure and rapid industrialization. As postulated by Cole and Neumayer (2004), the influx of migrants escalates the demand for residential and non-residential energy, while simultaneously adding to pollution. Urbanization was therefore introduced into the model as a determinant of CO2 emissions collaborating the works of Liu and Bae (2018), McGee and York (2018) and Ahmed et al. (2019). Finally, foreign direct investment inflows are associated with dirty technologies that escalate the rate of CO2 emissions in host countries (Dou and Han, 2019; Jun et al., 2018). Some foreign direct investment inflows are also associated with energy efficient innovations that aid in mitigating the emittance of CO2. Therefore, in line with Rafindadi et al. (2018), Chen et al. (2019) and Mert et al. (2019), foreign direct investment was adopted as a determinant of CO2 emanations. Considering the impact mechanisms for the variables selected, our proposed CO2 emission model which seems to be in tandem with broader literature is specified as;

$$CO2_{i,t} = \alpha_i + \beta_1 GDP_{it} + \beta_2 EC_{it} + \beta_3 URB_{it} + \beta_4 FDI_{it} + \mu_{i,t} \tag{1}$$

where CO2, GDP, EC, URB and FDI have already been defined as carbon emissions, economic growth, energy consumption, urbanization and foreign direct investments correspondingly; $\beta_1$, $\beta_2$, $\beta_3$ and $\beta_4$ are the parameters of the input series; $i$ symbolizes the countries under study; $t$ signifies the study period; and $\alpha_i$ and $\mu$ are the constant and error terms respectively. Logarithms on all the variables were taken to aid minimize the consequences of data fluctuations and heteroscedasticity. The new model took the form;

$$LnCO2_{i,t} = \alpha_i + \beta_1 LnGDP_{it} + \beta_2 LnEC_{it} + \beta_3 LnURB_{it} + \beta_4 LnFDI_{it} + \mu_{it} \tag{2}$$

where LnCO2, LnGDP, LnEC, LnURB and LnFDI, are the log conversions of CO2, GDP, EC, URB and FDI respectively. On the priori expectations of the study, $\beta_1$, $\beta_2$ and $\beta_3$ were projected to have positive influence on the emanation of CO2, whilst $\beta_4$ was predicted to have either a positive or a negative effect on the emittances of carbon. The Common Correlated Effects Mean Group (CCEMG) estimator was used to explore the elastic effects of the regressors on the response variable. The above estimator was used due to its efficiency to cross-sectional dependence and slope heterogeneity as evidenced in this study. Pesaran (2006) put forward the CCE model as;

$$y_{it} = \alpha_i + \beta_i x_{it} + c_i f_t + \delta_i \bar{x}_t + \eta_i \bar{y}_t + e_{it} \tag{3}$$

where

$$\bar{x}_t = \frac{1}{N}\sum_{i=1}^{N} x_{it}, \quad \bar{y}_t = \frac{1}{N}\sum_{i=1}^{N} y_{it} \tag{4}$$

Relying on equation (3), the CCE relation for the study became;

$$LnCO2_{it} = \alpha_i + \beta_1 LnGDP_{it} + \beta_2 LnEC_{it} + \beta_3 LnURB_{it} + \beta_4 LnFDI_{it} + c_i f_t + \delta_i \bar{x}_t + \eta_i \bar{y}_t + e_{it} \tag{5}$$

where $\beta_1$, $\beta_2$, $\beta_3$ and $\beta_4$ are the parameters of the regressors, $e_{it}$ and $\alpha_i$ are the error and constant terms correspondingly, and $f_t$ connotes common factors that are not observed. To help check the validity and reliability of the CCEMG estimates, the AMG estimator proposed by Eberhardt and Teal (2010) and Eberhardt and Bond (2009) was also employed. This estimator was engaged because, in the presence of heterogeneity and cross-sectional reliance, it produces efficient results.

## Data source

Panel data on the nineteen (19) member countries of the G20 for 1992 to 2014 was used for the study. The countries under study were Australia, Canada, Saudi Arabia, United States, India, Russia, South Africa, Turkey, Argentina, Brazil, Mexico, France, Germany, Italy, United Kingdom, South Korea, Indonesia, Japan and China. All the data used for this investigation were obtained from the database of the World Bank (WDI, 2020). The period

**Table 1.** Data description and measurement units.

| *Variable* | *Abbreviation* | *Measurement unit* | *Source* |
|---|---|---|---|
| Carbon emissions | CO2 emissions | metric tons per capita | WDI (2020) |
| Gross domestic product | GDP | GDP per capita (constant 2010 US$) | WDI (2020) |
| Energy consumption | EC | kg of oil equivalent per capita | WDI (2020) |
| Urbanization | URB | Urban population growth (annual %) | WDI (2020) |
| Foreign direct investments | FDI | net inflows (% of GDP) | WDI (2020) |

1992 to 2014 was used due to data limitations. Thus, some of the variables did not have data for periods below or above the chosen time frame. For instance, data on foreign direct investment for Russia were missing for most periods below 1992, whilst the country's data on energy consumption for most periods below 1990 were also missing. Additionally, data on economic growth for Russia for most periods below 1989 were missing, whilst Germany had missing data on CO2 emissions for most periods below 1991. Also, some of the countries had missing data on energy consumption from 2015 to 2019, whilst others had missing data on the same variable from 2016 to 2019. Finally, data on CO2 emissions for some of the countries were missing from 2015 to 2019, whilst others had data on the same variable missing from 2017 to 2019. In order to have a fully balanced data, investigate all the 19 member countries of the G20, and also able to use all the selected variables, the period 1992 to 2014 was considered for the study. Thus, the period was chosen based on the availability of data for the variables of concern. Table 1 gives further details on the studied variables.

## *Analytical procedure*

Cross-sectional correlations and heterogeneity among series play a key role in the selection of econometric methods for analysis. Therefore, as a first step the study tested for cross-sectional correlations among the residuals of the model using the Breusch and Pagan (1980) LM test, Pesaran (2004) scaled LM test and the Pesaran (2015) CD test. Afterwards, the Pesaran and Yamagata (2008) test was engaged to detect homogeneity or heterogeneity in the inclined coefficients. Thirdly, the CIPS and the CADF tests that are resilient to the above issues were undertaken to check the integration order of the series. The analysis then proceeded to the Westerlund and Edgerton (2007) and Pedroni (2004) tests to examine the cointegration attributes of the series. Afterwards, the CCEMG regression estimator was used to estimate the elastic effects of the regressors on the explained variable. The AMG estimates were also explored to help check the validity and reliability of the CCEMG results. Finally, the D-H causality test, efficient to correlations in cross-sections and heterogeneity issues was adopted to uncover the causal directions amid the series. Taken X and Y to be the explanatory and the explained variables respectively, then the D-H causality test is expressed officially as;

$$Y_{it} = \gamma_i + \sum_{m=1}^{M} \alpha_i^{(m)} Y_{it-m} + \sum_{m=1}^{M} \delta_i^{(m)} X_{it-m} + \varepsilon_{it} \tag{6}$$

where $M$ symbolizes lag length, $\gamma_i$ connotes distinct fixed effects, $\alpha_i{}^{(m)}$ signifies units differences, and $\delta_i{}^{(m)}$ indicates predictors' coefficients. Relying on equation (6), the following series of linear models were specified to help explore the causal connections amid the series;

$$\begin{aligned}\ln CO_{2_{i,t}} = \gamma_1 + \sum_{m=1}^{M} \alpha_1{}^{(m)} \ln CO_{2_{i,t-m}} + \sum_{m=1}^{M} \delta_1{}^{(m)} \ln GDP_{it-m} + \sum_{m=1}^{M} \delta_2{}^{(m)} \ln EC_{it-m} \\ + \sum_{m=1}^{M} \delta_3{}^{(m)} lnURB_{it-m} + \sum_{m=1}^{M} \delta_4{}^{(m)} lnFDI_{it-m} + \varepsilon_{it}\end{aligned} \tag{7a}$$

$$\begin{aligned}\ln GDP_{it} = \gamma_2 + \sum_{m=1}^{M} \alpha_2{}^{(m)} \ln GDP_{it-m} + \sum_{m=1}^{M} \delta_5{}^{(m)} \ln EC_{it-m} + \sum_{m=1}^{M} \delta_6{}^{(m)} \ln URB_{it-m} \\ + \sum_{m=1}^{M} \delta_7{}^{(m)} \ln FDI_{it-m} + \sum_{m=1}^{M} \delta_8{}^{(m)} \ln CO_{2_{i,t-m}} + \varepsilon_{it}\end{aligned} \tag{7b}$$

$$\begin{aligned}\ln EC_{it} = \gamma_3 + \sum_{m=1}^{M} \alpha_3{}^{(m)} \ln EC_{it-m} + \sum_{m=1}^{M} \delta_9{}^{(m)} \ln URB_{it-m} + \sum_{m=1}^{M} \delta_{10}{}^{(m)} \ln FDI_{it-m} \\ + \sum_{m=1}^{M} \delta_{11}{}^{(m)} \ln CO_{2_{i,t-m}} + \sum_{m=1}^{M} \delta_{12}{}^{(m)} \ln GDP_{it-m} + \varepsilon_{it}\end{aligned} \tag{7c}$$

$$\begin{aligned}\ln URB_{it} = \gamma_4 + \sum_{m=1}^{M} \alpha_4{}^{(m)} \ln URB_{it-m} + \sum_{m=1}^{M} \delta_{13}{}^{(m)} \ln FDI_{it-m} + \sum_{m=1}^{M} \delta_{14}{}^{(m)} \ln CO_{2_{i,t-m}} \\ + \sum_{m=1}^{M} \delta_{15}{}^{(m)} \ln GDP_{it-m} + \sum_{m=1}^{M} \delta_{16}{}^{(m)} \ln EC_{it-m} + \varepsilon_{it}\end{aligned} \tag{7d}$$

$$\begin{aligned}\ln FDI_{it} = \gamma_5 + \sum_{m=1}^{M} \alpha_5{}^{(m)} \ln FDI_{it-m} + \sum_{m=1}^{M} \delta_{17}{}^{(m)} \ln CO_{2_{i,t-m}} + \sum_{m=1}^{M} \delta_{18}{}^{(m)} \ln GDP_{it-m} \\ + \sum_{m=1}^{M} \delta_{19}{}^{(m)} \ln EC_{it-m} + \sum_{m=1}^{M} \delta_{20}{}^{(m)} \ln URB_{it-m} + \varepsilon_{it}\end{aligned} \tag{7e}$$

where $\gamma_1, \ldots, \gamma_5$ are constant parameters to be estimated, $\alpha_1, \ldots, \alpha_5$ represent autoregressive parameters, and $\delta_1, \ldots, \delta_{20}$ denotes parameters of the regressors. The D-H causality test comes out with two statistics, the $\bar{W}$-statistic and the Z-statistic. These statistics are computed as;

$$W_{N,T}^{HNC} = N^{-1} \sum_{i=1}^{N} W_{i,t} \tag{8}$$

$$Z_{N,T}^{HNC} = \frac{\frac{1}{\sqrt{N}}\left[\sum_{i=1}^{N} W_{i,t} - \sum_{i=1}^{N} E(W_{i,t})\right]}{\sqrt{\frac{1}{N}\sum_{i=1}^{N} Var(W_{i,t})}} \tag{9}$$

where $W_{i,t}$ epitomizes cross-sectional Wald statistic, and respectively, $E(W_{i,t})$ and $Var(W_{i,t})$ symbolizes the expectation and variance of the Wald test statistic.

## Empirical results

### Descriptive analysis

Descriptive statistics relating to the variables of concern are exhibited in Tables 2 and 3. From Table 2, economic growth had the maximum average value, whilst urbanization had the minimum average value. With respect to the skewness results, energy consumption, CO2 emissions, foreign direct investments and urbanization flattered negatively to the left, whilst that of economic growth flattered positively to the right. Based on the kurtosis outcomes, the distributions of foreign direct investments and urbanization were leptokurtic in shape (kurtosis values higher than 3), whilst that of CO2 emissions, energy consumption and economic growth were platykurtic in shape (kurtosis values lower than 3). Based on the skewness and kurtosis statistics, none of the distributions of the variables satisfied the assumption of normality. These findings collaborated the Jarque-Bera test's results that

**Table 2.** Descriptive statistics on study variables.

| *Statistic* | *LnCO2* | *LnGDP* | *LnEC* | *LnURB* | *LnFDI* |
|---|---|---|---|---|---|
| Mean | 1.8487 | 14.4220 | 7.8707 | 0.1567 | 0.2045 |
| Median | 2.1000 | 10.5535 | 8.1249 | 0.3365 | 0.5082 |
| Maximum | 3.0046 | 29.7505 | 9.0426 | 1.6255 | 2.5466 |
| Minimum | −0.2629 | 6.3886 | 5.8946 | −6.0980 | −7.2338 |
| Std. Dev. | 0.8297 | 8.1091 | 0.7882 | 1.0200 | 1.3242 |
| Skewness | −0.6856 | 1.0313 | −0.5985 | −1.6302 | −2.0667 |
| Kurtosis | 2.5747 | 2.1681 | 2.4839 | 7.2411 | 9.6218 |
| Jarque-Bera | 37.5243 | 90.0631 | 30.9422 | 521.0653 | 1109.487 |
| Probability | 0.0000a | 0.0000a | 0.0000a | 0.0000a | 0.0000a |
| VIF | – | 1.03 | 1.25 | 1.28 | 1.03 |
| Tolerance | – | 0.9682 | 0.8004 | 0.7808 | 0.9701 |
| LnCO2 | 1.0000 | | | | |
| LnGDP | 0.2185 | 1.0000 | | | |
| | (0.0000)a | | | | |
| LnEC | 0.9650 | 0.1316 | 1.0000 | | |
| | (0.0000)a | (0.0059)a | | | |
| LnURB | 0.3866 | −0.1372 | −0.4389 | 1.0000 | |
| | (0.0000)a | (0.0410)b | (0.0000)a | | |
| LnFDI | 0.0292 | 0.0655 | −0.0146 | 0.1428 | 1.0000 |
| | (0.0543)c | (0.1715) | (0.7611) | (0.058)c | |

Note: *a, b and c denote significance at the 1%, 5% and the 10% levels respectively.*

also affirmed the variables' distributions to be of non-normal shape. Further, there was no collinearity among the covariates based on the discoveries of the VIF and tolerance tests. Additionally, all the explanatory variables had significant loadings as per the findings of the Principal Components Analysis (PCA) displayed in Table 3, and were therefore relevant in predicting the emission of carbon in G20 countries. Lastly, the matrix of correlation between the series establishes a substantially positive liaison amid the emanation of carbon and all the predictors. This outcome portrays that, as economic growth, energy consumption, urbanization and foreign direct investments rose, CO2 emittances also surged and vice-versa.

## *Heterogeneity and cross-sectional dependence tests results*

Due to trade and other socio-economic activities, countries are related to each other in one way or the other. These tight connections might lead to cross-sectional correlations amid the nations. According to Mensah et al. (2020), the negligence of cross-sectional correlations might lead to erroneous estimates and inferences. Therefore, as a first step, three CD tests indicated in Table 4 were conducted. From the tests' results, the residuals of the model were cross-sectionally dependent. This implies spillovers could spread from one country to the other as a result of the strong economic ties between the nations. The discovery supports that of Mensah et al. (2019) and Musah et al. (2020a), but contrasts that of Li et al. (2020) whose investigation on listed non-financial body corporates in Ghana, affirmed

**Table 3.** Principal components analysis (PCA).

| *Component* | *Eigenvalue* | *Difference* | *Proportion* | *Cumulative* |
|---|---|---|---|---|
| Comp 1 | 1.52306 | 0.452136 | 0.3808 | 0.3808 |
| Comp 2 | 1.07093 | 0.206342 | 0.2677 | 0.6485 |
| Comp 3 | 0.864585 | 0.323162 | 0.2161 | 0.8646 |
| Comp 4 | 0.541424 | – | 0.1354 | 1.0000 |

*Eigenvectors (Loadings):*

| *Variable* | *Comp 1* | *Comp 2* | *Comp 3* |
|---|---|---|---|
| LnGDP | 0.3191 | 0.5796q | −0.7479k |
| LnEC | 0.6485p | 0.0572 | 0.3688 |
| LnURB | −0.6719p | 0.1379 | −0.1282 |
| LnFDI | −0.1615 | 0.8011q | 0.5368k |

Note: *p indicates significant loadings under component 1, q denotes significant loadings under component 2 and k represents significant loadings under component 3.*

**Table 4.** Residual cross-sectional dependence tests results.

| *Test type* | *Statistic* | *Prob.* |
|---|---|---|
| Breusch-Pagan LM | 846.3819 | 0.0000a |
| Pesaran scaled LM | 36.52047 | 0.0000a |
| Pesaran CD | 3.040031 | 0.0024a |

Note: ***a*** *denotes significance at the 1% level.*

independencies among the residuals of the studied model. Secondly, since the ignorance of heterogeneity could lead to biased estimates and extrapolations (Mensah et al., 2019), the researchers tested the heterogeneity assumption through the Pesaran-Yamagata test. The test's outcome portrayed in Table 5 affirmed the slope coefficients to be heterogeneous in nature. This indicates that the estimation of the elasticities as well as the causal connections amid the series has been heterogeneous across the countries. The outcome collaborates that of Mensah et al. (2019) whose research on Africa, provided evidence of the slope coefficients being heterogonous in nature.

## *Unit root and cointegration tests results*

According to Adamu et al. (2019) and Salehnia et al. (2020), series must assume a certain integration order before further analysis could be undertaken. Therefore, in line with the works of Musah et al. (2020a) and Mensah et al. (2019), the stationarity tests indicated in Table 6 were undertaken at the third stage. From the results, all the variables were first differenced stationary. This indicates that, the series were capable of generating more valid and reliable outcomes supporting that of Salehnia et al. (2020). The discoveries also implies, there could be cointegration affiliation amid the series in the long-run. Therefore, following the works of Musah et al. (2020b), the Westerlund and Edgerton bootstrap test alongside the Pedroni test were undertaken to assess the cointegration features of the variables. Relying on the discoveries portrayed in Tables 7 and 8, the series were significantly affiliated in the long-run. This outcome collaborates those of Li et al. (2020) and Erdoğan et al. (2020) whose studies affirmed cointegration relationship amid the variables of concern.

**Table 5.** Slope heterogeneity test results.

| *Test* | *Value* | *Prob.* |
|---|---|---|
| Delta tilde ($\tilde{\Delta}$) | 207.5 | 0.0506c |
| Adj delta tilde ($\tilde{\Delta}_{adj}$) | 9.36 | 0.0000a |

Note: *a and c imply significance at the 1% and the 10% levels respectively.*

**Table 6.** CIPS and CADF unit root test results.

| | *CIPS* | | | *CADF* | | |
|---|---|---|---|---|---|---|
| *Variable* | *Levels* | *First Diff.* | *Conclusion* | *Levels* | *First Diff.* | *Conclusion* |
| LnCO2 | −1.791 | −4.398a | I(1) | −1.637 | −3.006a | I(1) |
| LnGDP | −1.984 | −2.885b | I(1) | −2.223 | 2.546c | I(1) |
| LnEC | −1.851 | −4.565a | I(1) | −1.544 | −3.063a | I(1) |
| LnURB | −2.477 | −3.687a | I(1) | −2.677 | −3.282a | I(1) |
| LnFDI | −2.318 | −5.553a | I(1) | −2.659 | −2.919b | I(1) |

Note: *a, b and c denote significance at the 1%, 5% and the 10% levels respectively.*

**Table 7.** Westerlund ECM panel cointegration test results.

| *Statistic* | *Value* | *Z-value* | *P-value* | *Robust P-value* |
|---|---|---|---|---|
| Gt | −3.840 | −2.914 | 0.001a | 0.000a |
| Ga | −6.786 | 3.195 | 0.045b | 0.032b |
| Pt | −10.215 | −5.832 | 0.000a | 0.000a |
| Pa | −9.712 | −4.181 | 0.082c | 0.051c |

Note: *a, b and c denote significance at the 1%, 5% and the 10% levels respectively.*

**Table 8.** Pedroni residual cointegration test results.

| *Test Type* | *Value* | *Prob.* |
|---|---|---|
| *Within-dimension* | | |
| Panel v-Statistic | 0.1281 | 0.4490 |
| Panel rho-Statistic | 1.1836 | 0.8817 |
| Panel PP-Statistic | −2.9249 | 0.0517c |
| Panel ADF-Statistic | −4.7427 | 0.0000a |
| *Between-dimension* | | |
| Group rho-Statistic | 2.4687 | 0.9932 |
| Group PP-Statistic | −7.4223 | 0.0000a |
| Group ADF-Statistic | −3.4616 | 0.0323b |

Note: *a, b and c denote significance at the 1%, 5% and the 10% levels respectively.*

**Table 9.** CCEMG and AMG estimation results.

| | *CCEMG* | | *AMG* | |
|---|---|---|---|---|
| *Variable* | *Coefficient* | *Prob.* | *Coefficient* | *Prob.* |
| LnGDP | 0.1450 | 0.026b | 0.0589 | 0.044b |
| LnEC | 1.1777 | 0.000a | 1.1171 | 0.000a |
| LnURB | 0.0152 | 0.057c | 0.0112 | 0.026b |
| LnFDI | 0.0025 | 0.030b | 0.0059 | 0.021b |
| Wald chi2 | 283.93 | 0.000a | 226.31 | 0.000a |
| RMSE | 0.019 | | 0.024 | |

Notes: *LnCO2 emissions is the explained variable, and a, b, c denote significance at the 1%, 5% and the 10% levels respectively.*

## *Model estimation results*

After substantiating the series to be materially related in the long-term, the elastic effects of economic growth, energy consumption, urbanization and foreign direct investments on the emanation of CO2 were first explored through the CCEMG estimator. From the discoveries shown in Table 9, economic growth escalated CO2 emittances in the countries by 0.145% at the 1% connotation level. Also at the 1% impact level, energy consumption promoted the emanation of carbon by 1.178% in the nations. Similarly, urbanization substantially raised the emanation of CO2 at the 10% level. A 1% upsurge in urbanization escalated the rate of

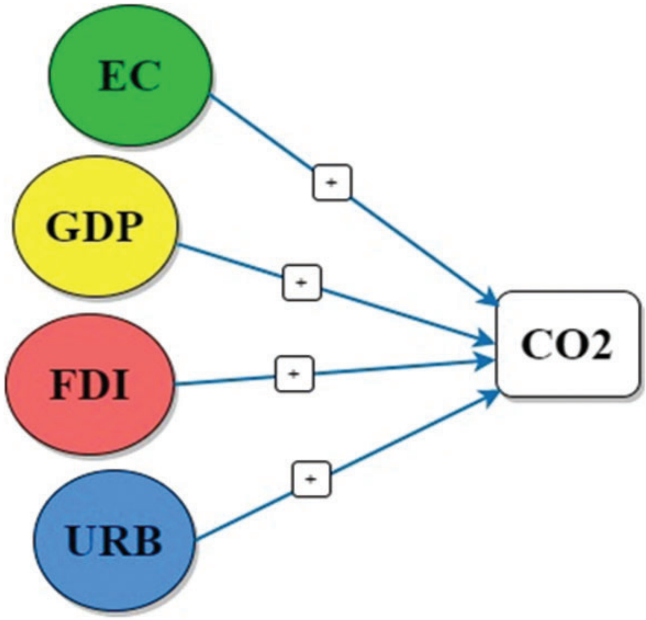


**Figure 1.** Elastic effects of economic growth, energy consumption, urbanization and foreign direct investments on CO2 emissions. Note: + denote positive influence on CO2 emissions.

emissions by 0.015%, when all other factors were held fixed. Further, foreign direct investments promoted the rate of emissions in the countries by 0.003% at the 1% relevance level. Lastly, the value of the Wald chi2 was statistically material at the 1% level ($p = 0.000$). This indicates that, economic growth, energy consumption, urbanization and foreign direct investments had a combined influence on CO2 emittances in the countries. The RMSE value of 0.019 further proves that, the proposed CO2 emissions model had a very high predictive power. For robustness purpose, the AMG estimates were also explored. From the results shown in Table 9, the estimates of both the AMG and that of the CCEMG were similar in terms of sign, justifying that the results were vigorous. Specifically, a percentage upsurge in economic growth, energy consumption, urbanization and foreign direct investments escalated the rate of emissions in the countries by 0.059%, 1.117%, 0.011% and 0.006% correspondingly. Also, the Wald chi2 value of 226.31was statistically material at the 1% level ($p = 0.000$), demonstrating that, the explanatory variables had a combined significant influence on the rate of emissions in the countries. The RMSE value of 0.024 finally substantiates that the proposed model had a very high predictive power. The elastic effects of explanatory variables on the explained variable are shown in Figure 1.

## *Causality tests results*

A prove of long-run equilibrium affiliations amid series implies, the variables might cause each other in one way or the other. Therefore, as a final step, the causal directions amid the series were explored through the D-H causality test. From the causalities amid the input and the response series, depicted in Table 10 and Figure 2, a bilateral causal relation was revealed between economic activities and CO2 emanations. Also, a reciprocal liaison was

**Table 10.** Pairwise Dumitrescu Hurlin panel causality tests results.

| *Null Hypothesis:* | *W-Stat.* | *Zbar-Stat.* | *Prob.* |
|---|---|---|---|
| LnGDP does not homogeneously cause LnCO2 | 4.3201 | 8.0622 | 7.E-16a |
| LnCO2 does not homogeneously cause LnGDP | 3.0728 | 4.9222 | 9.E-07a |
| LnEC does not homogeneously cause LnCO2 | 3.2392 | 5.3409 | 9.E-08a |
| LnCO2 does not homogeneously cause LnEC | 3.5046 | 6.0091 | 2.E-09a |
| LnURB does not homogeneously cause LnCO2 | 2.9020 | 4.4921 | 7.E-06a |
| LnCO2 does not homogeneously cause LnURB | 2.7841 | 4.1953 | 3.E-05a |
| LnFDI does not homogeneously cause LnCO2 | 2.2619 | 3.3633 | 0.0716c |
| LnCO2 does not homogeneously cause LnFDI | 1.8368 | 0.8105 | 0.1702 |
| LnEC does not homogeneously cause LnGDP | 2.5010 | 3.4826 | 0.0005a |
| LnGDP does not homogeneously cause LnEC | 4.9858 | 9.73788 | 0.0000a |
| LnURB does not homogeneously cause LnGDP | 3.7786 | 6.6988 | 2.E-11a |
| LnGDP does not homogeneously cause LnURB | 4.4712 | 8.4425 | 0.0000a |
| LnFDI does not homogeneously cause LnGDP | 1.5310 | 1.0631 | 0.2877 |
| LnGDP does not homogeneously cause LnFDI | 2.6367 | 3.8241 | 0.0001a |
| LnURB does not homogeneously cause LnEC | 2.7851 | 4.1978 | 3.E-05a |
| LnEC does not homogeneously cause LnURB | 4.0703 | 7.4334 | 1.E-13a |
| LnFDI does not homogeneously cause LnEC | 1.9433 | 2.0785 | 0.0377b |
| LnEC does not homogeneously cause LnFDI | 1.7701 | 1.6425 | 0.1005 |
| LnFDI does not homogeneously cause LnURB | 1.5080 | 0.9827 | 0.3258 |
| LnURB does not homogeneously cause LnFDI | 1.5813 | 1.1672 | 0.2431 |

Notes: *LnCO2 emissions is the explained variable, and* ***a, b, c*** *denote significance at the 1%, 5% and the 10% levels respectively..*

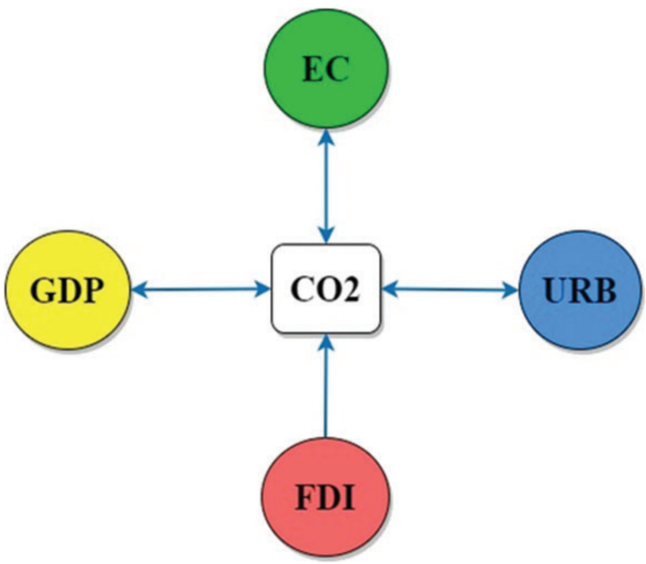


**Figure 2.** Direction of causalities between the response and the input variables. Note: ↔ signify a two-way causality between variables and ← denote a one-way causality between variables.

flanked between energy usage and $CO_2$ emittances. Likewise, urbanization and $CO_2$ emissivities were intertwined strongly and substantially in the countries. Finally, a one-sided movement from foreign direct investments towards $CO_2$ emittances was unveiled. Variations in the findings shows the heterogeneity in the causal connexion amid the series.

## Discussions

The elastic effects of the explanatory variables on the explained variable were explored through the CCEMG and the AMG regression estimators. The discoveries affirmed economic growth as a major promoter of $CO_2$ emanations in G20 countries. This suggests that a rise in economic growth led to a rise in the functioning of the country's primary factors of production like labour, capital and land among others. However, the functioning of these economic activities largely depends on the consumption of high volumes of environmentally unfriendly energy sources which escalate the rate of $CO_2$ emissions. The above finding collaborates that of Nkengfack and Kaffo (2019) and Ito (2017), but contrasts those of Bekhet et al. (2017) and Shoaib et al. (2020). Also, energy consumption raised the level of $CO_2$ emittance in the nations. This outcome indicates that the countries depend primarily on environmentally unfriendly energy sources to boost their productivity. Put simply, an upsurge in the production of goods and services are associated with the use of high volumes of dirty energy that escalates the rate of $CO_2$ emanations in the nations. The discovery is consistent to those of Jian et al. (2019) and Nkengfack and Kaffo (2019), but conflicts that of Zafar et al. (2019) and Karasoy and Akçay (2019). Similarly, urbanization escalated $CO_2$ emissivities in the countries. This outcome suggests that the movement of people to urban centers lead to more industrialization, expansion in businesses, and the construction of roads, bridges, hospitals and markets among others, that are very reliant on the consumption of dirty energy, thereby intensifying the nations' $CO_2$ emanations. Another potential explanation is that urbanization does not establish energy usage opportunities and a consequent reduction in $CO_2$ emittances. Further, people in urban centers in the countries have no greater concern for environmental sustainability and spend more on products and practices that are not friendly to the environment. This discovery conflicts that of McGee and York (2018) and Ali et al. (2017), but supports that of Caliskan (2015) and Shahbaz et al. (2014). Finally, foreign direct investments increased the countries' $CO_2$ emanations. This finding indicates that the countries have poor environmental controls, which enable high polluting industries to operate there. In other words, the countries do not have good environmental initiatives that could curtail the transition of dirty technologies from foreign entities. The outcome supports that of Ren et al. (2014) and Seker et al. (2015), but contradicts that of Rafindadi et al. (2018) and Chen et al. (2019).

The causal connexion between the variables were examined through the D-H causality test. On the causal liaison between the explained and the explanatory variables (which was our major area of focus), a mutual affiliation amid economic growth and $CO_2$ emittances was revealed. A potential explanation for this outcome is that expanding economic development in the countries would promote $CO_2$ emanations and vice-versa. Likewise, any effort to reduce $CO_2$ emittances would decrease the pace of the nations' economic progress. The discovery collaborates that of Cherni and Jouini (2017) and Mirza and Kanwal (2017), but conflicts those of Ali et al. (2017) and Shahbaz et al. (2016). Also, a bilateral connexion amid energy consumption and $CO_2$ emittances was disclosed. This indicates that the use of energy mutually reinforces the emanation of $CO_2$ in the nations. The outcome disagrees with those of Aye et al. (2017) and Mohiuddin et al. (2016), but supports that of Mesagan and Nwachukwu (2018) and Sekrafi and Sghaier (2018). Additionally, a bidirectional causal liaison between urbanization and CO2 emissions was disclosed. This outcome indicates that the countries' CO2 emittances are highly dependent on the pace at which people migrate to urban areas to pursue jobs and other livelihoods. In the same way, urbanization is also highly reliant on the countries' CO2 emanations. Therefore, any attempt to curb the rate of urbanization would lead to a reduction in the rate of carbon emittances in the nations. This outcome supports that of Zhang and Xu (2017) and Bekhet and Othman (2017), but contradicts that of Mesagan and Nwachukwu (2018) and Ma et al. (2017). Finally, a one-headed causation from foreign direct investments to the emanation of CO2 was unfolded. This result indicates that investments made in the countries are related to environmentally unfriendly innovations that surges the countries' rate of emittances. The outcome also indicates that the two variables are not intertwined, since foreign direct investments does not depend on CO2 emanations in the countries. This result is inconsistent to that of Omri et al. (2014) for selected 54 countries in the globe, Lee (2013) for 19 nations of the G20 and Zhang (2011) for China.

## Conclusions

This research explored the linkage between economic growth, energy usage and CO2 emittances in G20 countries. In order to yield accurate and reliable outcomes, more robust technques of econometrics were used. From the heterogeneity and cross-sectional dependence tests, the panel was heterogeneous and cross-sectionally correlated. Also, all the series were I(1) after first difference, and substantially related in the long-term. Additionally, the CCEMG and the AMG regression estimates affirmed economic growth and energy consumption as key promoters of CO2 emanations in the countries. Similarly, control variables urbanization and foreign direct investments escalated the rate of emissions in G20 countries. The causal liaison amid the explained and the explanatory variables were explored through the D-H causality test, and from the discoveries a bilateral connexion amid economic development and CO2 emittances, between energy usage and CO2 emanations; and between urbanization and CO2 emissions were unfolded. Howerver, the cusation amid foreign direct investments and CO2 emissions was one-way moving from foreign direct investments to the emission of carbon in the countries. The study discvered that economic growth escalated the rate of CO2 emissions in the countries. This implies economic activities undertaken in the countries are connected to the consumption of large quantities of environmentally unfriendly energy sources that increases the rate of emissions in the countries. Based on this finding, authorities need to implement policies that simultaneously advance economic growth and also improve environmental sustainability in the countries. This goal can be accomplished by revising energy policies to minimize dependencies on nonrenewable energies like fossil fuels, coal and natural gas among others; whilst promoting the use of renewable energies like solar, wind, biogas, biomass, and hydropower just to mention a few. These clean energy sources will not only minimize the emanation of carbon, but will also contribute to the nations' economic growth as postulated by Wang and Wang (2020). Additionally, environmental policies should be well planned, organized, and implemented in compliance to the countries' macroeconomic objectives. When this is accomplished, energy conservation policies implemented to minimize the emanation of CO2 will improve the countries' economic growth.

Also, energy consumption led to more CO2 emissions in the countries. This outcome is not astounding, since most G20 countries are embedded with a lot of industries that rely primarily on high polluting energies to advance their undertakings. As a recommendation, energy efficient policies that promote environmental quality should be implemented in the countries. The countries should also have transparent and precise policies that could promote renewable energy use. A strategy like providing appropriate policy support for technological developments could be of immense merit to the nations. Further, the strategy of carbon capture storage, when well adopted, could benefit the countries tremendously in the production of biomass energy. Additionally, urbanization raised CO2 emittances in the nations. This outcome suggests that the migration of people to urban centers lead to more industrialization, business expansion, and the construction of roads, bridges, hospitals, and markets among others, that are highly dependent on dirty energy, thus increasing the rate of emissions in the countries. Therefore, it is recommended that authorities should focus on job creation and improving the living standards of rural people. This will reduce the rate at which people migrate from rural to urban centers. Furthermore, providing rural communities with social amenities would also help to minimize the rate of urbanization, thereby abating the level of emissions in the countries. Finally, foreign direct investments promoted the emission of CO2 in the countries. This result suggests lax environmental controls in the countries that allow highly polluting industries to operate there. As a recommendation, serious regulations should be formulated by authorities to help curtail environmental harm caused by foreign investors in the countries. Also, the nations should be more concerned about the quality of the environment and should not trade-off between economic growth and environmental quality, by easing regulations to draw more foreign direct investments inflows.

## Abbreviations

Carbon emissions (CO2 emissions); Economic growth (GDP); Energy Consumption (EC); Urbanization (URB); Foreign Direct Investments (FDI); Common Correlated Effects Mean Group (CCEMG); Common Correlated Effects (CCE); Augmented Mean Group (AMG); Cross-sectional Dependence (CD); Lagrangian Multiplier (LM); Cross-sectionally Augmented Dickey-Fuller (CADF); Cross-sectional Im, Pesaran and Shin (CIPS); Dumitrescu and Hurlin causality test (D-H causality test); Root Mean Square Error (RMSE).

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