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CAN CO_2 EMISSIONS AND ENERGY CONSUMPTION DETERMINE THE ECONOMIC PERFORMANCE OF SOUTH KOREA? A TIME-SERIES ANALYSIS

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Abstract

Following the United Nations Sustainable Development Goals (UN-SDGs) which emphases on relevant concerns that encompass access to energy (SDG-7) and sustainable development (SDG-8). This research tends to re-examine the interaction between urbanization, CO_2, capital formation, energy use, and economic growth in South Korea, which has not yet been assessed using the recent econometric techniques and data stretching between 1965 and 2019. The present study utilized the Autoregressive distributed lag (ARDL), Dynamic Ordinary Least Square (DOLS), and Fully Modified Ordinary Least Squares (FMOLS) methods while for the causality direction the Gradual shift and Wavelet coherence method are utilized. The ARDL bounds test uncovers a long-run linkage between the variables of interest. Empirical evidence shows that emissions spur economic growth. Thus, there is also a necessity to change the energy mix in South Korea to renewables, based on increasing environmental awareness across the globe, to enable the use of sustainable energy sources and establish an environmentally sustainable ecosystem. Moreover, the energy-induced

growth hypothesis is validated. This result is resonated by the causality analysis where energy consumption drives GDP one-way in South Korea. This suggests that South Korea cannot embark on energy conservative policies, as such actions will hurt economic progress. Additionally, unidirectional causality is seen between urbanization, trade opens, and economic growth. These findings have far-reaching consequences for GDP growth and macroeconomic indicators in South Korea.

Keywords: CO_2 Emissions; Sustainable Growth; Urban Population; Energy Use; South Korea.

1. Introduction

To minimize the awful situation confronting the whole globe, the menace of global warming has raised the amount of consciousness from all works of life. Several forums and organizations have been developed inline and via the United Nations (UN) system and the path to climate neutrality (Udemba et al. 2021). Human actions on the surface of the planet are the sole contributor to global warming, resulting in environmental destruction due to global warming (Kirikaleli & Adebayo, 2020). With the advent of global warming, countries have been charged with individual and collaborative ways of thought and working towards mitigating global warming. Climate change is a global problem that has strengthened international and domestic consciousness to mitigate the growing trend (Olanrewaju et al. 2021). Emissions from diverse sources of energy, in particular fossil fuels, and other non-renewable sources of energy, are dispersed as contaminant components into the air. These are liable for adversely affecting both the climate and the welfare of the people. Not only are the pollutants in the environment, but they also have connections to bodies of water and wetlands that damage or poison marine life. The pollution of both the water bodies and air have a detrimental impact on the society through the living condition, health, malnutrition of the populace (Zhang et al. 2021; Udemba et al. 2021).

Growth in the economy is characterized as causing the disastrous impact of pollution among several measures considered. Several economic practices, both directed at and based on economic growth, contribute to emissions of pollutants (Ayobamiji & Demet, 2020; Udemba, 2020). Such practices from multiple sectors (petroleum sector, manufacturing, oil extraction, agriculture) of the economy that cause GDP growth triggers pollution (Umar et al. 2020). These pollutions from various sources and economic sectors impact human wellbeing negatively with various forms of diseases such as cancer, gaseous disease, and heart disease (Adedoyin et al. 2020). Manufacturing practices such as the use of heavy-duty equipment with the potential to burn huge amounts of fossil fuels, production process, delivery of products from the point of origin to the last or final customer with vehicles releasing CO2 emissions via exhaust pipes, waste dumping in bodies of water, electricity generation using other fossil fuels and coal lead to environmental degradation.

Since 2016, South Korea's total energy use has stayed stable after a period of constant growth (2.7%/year between 2000 and 2016). The driving force of South Korea's economic performance is oil and coal which accounts for 37%, and 26% of energy needs respectively. This shows the reliance of the South Korean economy on oil and coal as an energy source. In 2019, South Korea consumed 2.5million per day of petroleum and other liquids, ranking it the

8th largest consumer globally (EIA, 2020). This implies that, as a consequence of the rising demand for oil and coal in South Korea, CO2 emissions will certainly rise. Presently executed policies are projected to result in an emissions level of 665 to 743 $MtCO_2e$/year in 2030 subject to the ongoing impact of the COVID-19 crisis, without pollutions from LULUCF[1] (EIA, 2020). In its NDC, South Korea is officially committed to achieving 539 MtCO2e/year except for LULUCF. To achieve this target, South Korea will have to greatly improve its policies on climate, even more so if the government is concerned about implementing carbon neutrality by 2050, such as amending and enhancing its 2030 NDC to be compliant with the Paris accord. Based on the fascinating energy-mix of South Korea, the present research aims to examine the effects of the positive development and growth of South Korea, with an emphasis on the energy consequences of South Korea's economic performance via urbanization, gross capital formation, and use of energy. This research, therefore, explores the effect of CO2 pollution, urbanization, gross capital development, and use of energy on South Korea's economic performance.

It is important to recognize that, as a foremost economy regarding growth, it is necessary to explore the economy and render appropriate suggestions, based on analytical results, on economic sustainability. Based on the results, a detailed analysis of the sustainability of the South Korean economy will allow us to develop sustainable policies to answer questions including (a) Can South Korea diversify its policies regarding energy mix by embracing renewable energy to boost its green economy? (b) Can South Korea allow innovative pollutions mitigating measures without weakening sustainable economic development? It is also essential to remember that, as the South Korean economy grows, the role of the nation in the international rankings of CO_2 is very susceptible and the levels are rising at the same rate as those of other nations considered to be the major global emitters such as India, China, US, Japan, and Russia. In South Korea and Japan, which have the same economic characteristics and demographic composition, there is a disparity between the trend of output growth and the level of pollution. In both countries, this pattern has contributed to emissions of CO_2. That being said, considering the rapid population growth rate, there has been a serious effort to mitigating the detrimental consequences of global warming without involving GDP growth. This is the inspiration for researchers to investigate the variables illustrated in this report, as we strive to utilize the implications of this research as a policy for government administrators and stakeholders.

Given this progress, in midst of the optimistic and substantial growth of the South Korean economy, there has been limited emphasis on examining the importance of this pattern. Despite this, this research is intended to examine the economic performance in South Korea amid CO2 emissions. The current research is distinct from the existing studies because it accounts for other economic growth determinants such as energy usage, CO_2 emissions, gross capital formation, and urbanization. This report expands/complements the discussion in the South Korean economy on the growth-energy and pollution nexus and expands on the research for India by Udemba et al. (2021). The research is inspired by the Sustainable Development Goals (SDGs-7, 8, 12, and 13) and discusses specific energy use concerns (SDG-7) with a particular emphasis on green and sustainable use of energy (SDGs 7 and 12) to meet the 2020 Agenda. This is to avoid problems associated with economic growth (SDGs-8) and climate change (SDGs-13).

[1]Land use, land use change and forestry

The present research is considered especially timely and deserving of inquiry, particularly in the present age in which responsible energy use and environmental protection are increasingly being targeted.

`The concluding part of this report is planned in the following ways: a short synopsis of the previous studies and theoretical framework is depicted in Section 2. Section 3 presents the data and the methodologies, whereas Section 4 presents analytical results. Section 5 presents the conclusion and policy directions.

2. Literature Review

2.1. Empirical Review

An overview of the relevant literature on this topic will be discussed by reviewing the connections observed between the dependents variable (GDP) and its regressors (CO_2 emissions, urbanization, gross capital formation, and energy use). Research on the relation between GDP and these regressors have not reached a consensus due to mixed outcome, causing an increase in interest to this subject matter. The study of Teng et al. (2020) found that GDP increases CO_2 emission for ten different OECD economies over the coverage between 1985 and 2018. However, Ayobamiji & Kalmaz (2020) employed the wavelet technique in capturing the time-frequency dependency between CO2 and real output, which is consistent with the results of Teng et al. (2020). Aye & Edoja (2017) shows there is a negative link between GDP and CO_2 emission in 31 developing countries. Salahuddin et al (2018) show no interaction between CO_2 and real output In Kuwait, Wasti & Zaidi (2020) concluded that energy consumption and CO_2 emission accelerate GDP. Chontanawat (2020) and Gorus & Aydin (2019) suggest no causal association between CO_2 and real GDP in ASEAN economies for the period 1971 to 2015. Kirikkaleli (2020), Aydoğan & Vardar (2020), and Jafari et al. (2015) revealed a one-way casual interaction from GDP to CO_2 emission. However, Gao & Zhang's (2021)'s study showed that there is a unidirectional causal link from CO_2 emission to GDP but a bidirectional causal link between CO_2 emission and GDP was revealed by Wu et al. (2018). Bouznit & Pablo-Romero (2016) examined the interaction between CO_2 emission and GDP in Algeria for the period of 1970 to 2010, utilizing the ARDL. The result shows there is a positive association between CO_2 emission and GDP. The study of Adebayo & Odugbesan (2020) in South Africa also reveals a positive interaction between CO_2 emission and GDP. Al-Mulali (2011) examined a positive interaction between CO_2 emission and GDP in MENA. Furthermore, there is evidence of a two-way causal link between CO_2 emission and GDP. Awosusi et al. (2020) employed panel data from 1980 to 2018 for MINT economies. The result shows that there is no significant link between CO_2 emission and GDP. However, GDP tends to granger cause CO_2 emission. Adebayo (2020) also employed the ARDL and wavelet coherence to examine the long run and causal relationship between CO_2 emission and GDP in Mexico. The result shows a positive link between these variables. For the causality, there is a two-way interaction between CO_2 emission and GDP. Zhang et al.'s (2021) study reveal a different causal interconnection between CO_2 emission and GDP in Malaysia, which is a one-way link from GDP to CO_2 emission.

The study of Khobai & Le Roux (2017) established a bidirectional link between GDP and energy usage. Muhammad (2019) examined the link between energy usage and GDP in MENA economies from 2001 to 2017, suggesting a negative interaction between energy use and GDP. Shahbaz et al (2018) established a positive interaction between energy consumption and GDP in the top ten energy-consuming economies utilizing the quantile-on-quantile (QQ) approach for the period 1960Q1 to 2015Q4. This is consistent with the study done by Magazzino (2018) in Italy, Ahmed et al. (2013). Mutascu (2016) explored the causal interaction between GDP and energy use in G7 nations. The author revealed a bidirectional link between GDP and energy use in the United States, Canada, and Japan but no causality was evident in the United Kingdom and Italy. Yang & Zhao (2014) examined the temporal interaction between energy consumption and GDP from 1970 to 2008 in India, utilizing the Granger causality tests and DAG. The author revealed that there is a unidirectional linkage from energy consumption to GDP. Faisal et al. (2016) utilized the TY causality to examine the link between GDP and energy consumption in Russia. The authors revealed no causal link between these two variables. Ha & Ngoc (2020) also employed Toda-Yamamoto causality on data covering the period from 1971 to 2017 in Vietnam. The authors revealed a two-way causal link between these GDP and energy use. Baz et al (2019) confirm a positive shock moving from energy consumption to GDP in Pakistan from 1971 to 2014. Rahman et al. (2020) revealed energy consumption positively affects GDP in China covering the period from 1981-2016.

The study of Nathaniel & Bekun (2020) examined the association between urbanization and GDP in Nigeria covering the period from 1971 to 2014, employing Bayer and Hanck cointegration tests, ARDL, FMOLS, DOLS, CCR, and VECM Granger causality. Urbanization negatively inhibits GDP and a bidirectional link between urbanization and GDP. Nguyen & Nguyen (2018) found urbanization positively affects GDP in ASEAN. Ali et al. (2020) examined the association between urbanization and GDP using the Maki cointegration test, FMOLS, DOLS, CCR, VECM granger causality covering the period from 1971 to 2014. The authors found that urbanization hinders GDP in Nigeria and unidirectional causality from urbanization to GDP. Zheng & Walsh (2019) concluded that urbanization is a major contributor to GDP in China. Yang et al. (2017) found a positive association between GDP and urbanization.

For the linkage between gross capital formation and GDP growth numerous studies have been conducted, however, their findings are mixed. For instance, Topcu et al. (2020) explore the interaction between gross capital accumulation and GDP by using the Panel Vector (PVAR) covers the period between 1980 and 2018 for 124 economies. The author concludes the impact of gross capital formation differs based on the countries income level. Etokakpan et al. (2020) examined the association between gross capital accumulation and GDP in Malaysia covering the period 1980-2014, employing Bayer and Hanck cointegration tests, ARDL, and Granger causality. The authors concluded that an increase in gross capital formation will increase GDP. Kong et al. (2020) employed recent panel techniques to examine the relationship between gross capital formation and GDP for 39 African economies. The authors establish a positive link between gross capital formation and GDP. Furthermore, a bidirectional causal link was also evident between these two variables. Boamah et al (2018) also found a similar result for 18 Asian nations, employing the panel data covering 1990 to 2017. Table 1 depicts the synopsis of related studies.

Table 1: Synopsis of Studies				
Investigator (s)	Timeframe	Nation (s)	Technique(s)	Findings
CO_2 and GDP				
Teng et al. (2020)	1985-2018	10 OECD economies	PMG ARDL	$CO_2 \rightarrow$ GDP (+)
Zhang et al. (2021)	1960–2018	Malaysia	Maki cointegration, wavelet, and Gradual shift	GDP $\rightarrow CO_2$ (+) GDP $\rightarrow CO_2$
Adebayo and Odugbesan (2020)	1971-2016	South Africa	ARDL &Wavelet Coherence	$CO_2 \rightarrow$ GDP (+)
Al-Mulali (2011)	1980-2009	MENA	Panel Granger causality	$CO_2 \leftrightarrow$ GDP (+)
Ayobamiji & Kalmaz (2020)	1971-2015	Nigeria	ARDL, FMOLS, DOLS, Wavelet Coherence	$CO_2 \rightarrow$ GDP (+)
Wasti & Zaidi (2020)	1990-2014	Kuwait	ARDL	$CO_2 \rightarrow$ GDP (+)
Aye & Edoja (2017)	1971-2013	31 Emerging Nations	Panel Techniques	$CO_2 \rightarrow$ GDP (-)
Kalmaz & Kirikkaleli (2019)	1960-2016	Turkey	ARDL, FMOLS, DOLS, Wavelet Coherence	$CO_2 \rightarrow$ GDP (+)
Kirikkaleli (2020)	1950–2016.	China	Maki cointegration, wavelet, and Gradual shift	$CO_2 \rightarrow$ GDP
Bouznit & Pablo-Romero (2016)	1970-2010	Algeria	ARDL	$CO_2 \rightarrow$ GDP (+)
Aydoğan & Vardar (2020)	1990-2014	E-7	Panel VECM	$CO_2 \rightarrow$ GDP
Wu et al. (2018).	1995- 2017	World	PRISMA	$CO_2 \leftrightarrow$ GDP
Adebayo (2020)	1971-2016	Mexico	ARDL &Wavelet Coherence	$CO_2 \leftrightarrow$GDP (+)
Jafari et al. (2015)	1980-2007	Bahrain	TY causality	$CO_2 \rightarrow$ GDP
Salahuddin et al (2018)	1980–2017	South Africa	ARDL	$CO_2 \neq$ GDP
Adebayo et al. (2020)	1980-2018	MINT economies	ARDL and Panel Granger causality	$CO_2 \neq$ GDP
Adebayo & Akinsola (2020)	1971-2016	Thailand	ARDL &Wavelet Coherence, Granger and Toda-Yamamoto causality	$CO_2 \rightarrow$ GDP (+) $CO_2 \rightarrow$ GDP
Gao & Zhang (2021)	1980–2010	13 Asian developing countries	FMOLS and Panel Granger causality tests	$CO_2 \rightarrow$ GDP
EC and GDP				
Shahbaz et al (2018)	1960Q1 to 2015Q4	top 10 energy-consuming countries	quantile-on-quantile (QQ) approach	EC $\rightarrow$ GDP (+)

Khobai & Le Roux (2017)	1971-2013	South Africa	Johansen cointegration and VECM Granger causality tests	EC ↔ GDP
Ha & Ngoc (2020)	1971-2017	Vietnam	ARDL and Toda-Yamamoto causality	EC ↔ GDP
Rahman et al. (2020)	1981-2016	China	Hatemi-J and FMOLS	EC → GDP (+)
Baz et al (2019)	1971-2014	Pakistan	NARDL	EC → GDP (+)
Faisal et al. (2016)	1990-2011	Russia	Toda-Yamamoto causality	No causal link
Yang & Zhao (2014)	1970 - 2008	India	Granger causality and DAG	EC → GDP
Mutascu (2016)	1970–2012	G7 economies	Granger causality tests	EC ↔ GDP
Muhammad (2019)	2001-2017	MENA	MENA	EC → GDP (-)
Urban and GDP				
Nathaniel & Bekun (2020)	1971 -2014	Nigeria	Bayer and Hanck cointegration tests, ARDL, FMOLS, DOLS, CCR and VECM Granger causality	Urban ↔GDP (-)
Nguyen & Nguyen (2018)	1971-2014	ASEAN	D-GMM and PMG	Urban →GDP(+)
Ali et al. (2020)	1971-2014	Nigeria	Maki cointegration, FMOLS, DOLS, CCR and VECM Granger causality	Urban→ GDP (-)
Yang et al. (2017)	2000-2010	China	Pooled Ordinary Least Squares (POLS), Fixed Effects (FE), and Random Effect (RE	Urban →GDP (+)
Zheng & Walsh (2019)	2001–2012	29 provinces in China	FE and sys-GMM estimated methods	Urban →GDP (+)
GCF and GDP				
Topcu et al. (2020)	1980-2018	124 countries	PVAR	GCF → GDP (+)
Etokakpan et al. (2020)	1980-2014	Malaysia	Bayer and Hanck cointegration tests, ARDL and Granger causality	GCF → GDP (+)
Zhang et al. (2021)	1971-2016	Malaysia	ARDL, Wavelet Coherence, Gradual Shift	GCF → GDP (+)
Kong et al. (2020)	1997-2017	39 African countries	AMG and CCEMG	Urban → GDP(+) Urban ↔GDP (+)
Boamah et al (2018)	1990-2017	18 Asian nations	POLS	GCF → GDP (+)
Note EC: Energy Consumption, GDP: Economic Growth, CO_2: Carbon Emission, → (+): Positive relationship, → (-): Negative relationship, →: One-way causality, ↔: Bidirectional causality, Urban: Urbanization, GCF: Gross Capital Formation.				

2.2. Theoretical Framework

This study's theoretical work is based on the EKC which was built on the Kuznets curve of Simon Kuznets (1955), which was centered on income inequality. This theory explains the increasing trend of inequality and income per capita. There is a turning-point along the curve that shows where the farmers' per capita income, who exit the farming practices to take up white-collar jobs in urban regions is increasing, which closes the large gap between rich and poor. Environmental economist such as (Panayotou, 1997; Grossman and Krueger, 1991) improved on this theory by examining the association between economic growth and environmental quality. The effect of GDP growth on the quality of the environment of any economy arises in 3 phases- scale effect, structural effect, and composite effects. In the first phase, environmental degradation is experienced but reaching a point (turning point), the environmental quality begins to improve due to development in innovations and increasing environmental consciousness. This first phase is termed the scale effects. This phase is related to developing nations because non-renewable energy sources are used in promoting their economic and production activities. The structural and composite effects are regarding as the turning point. This is associated with developed countries, where most of their economic activities are service and technology-driven.

3. Data and Methodology

3.1. Data

The present research explores the impact of CO_2 emissions (CO_2) on economic growth (GDP) and also the role of gross capital formation (GCF), energy use (EC), and urbanization (URB) in South Korea using data spanning between 1965 and 2018. In the case of South Korea, the current research was conceived with the perspective of examining the connections between GDP growth, CO2 pollution, urbanization, and energy use. The empirical modeling is based on the ARDL technique. This analysis is based on the study by Udemba (2020) and Nathaniel et al. (2020) by adjusting for further catalysts of growth that have been overlooked in literature including growth theory caused by the urban population. As shown in the model of Solow growth regarding capital and labor contribution. For the cases in South Korea that have the same economic characteristics, urban populations are included in our sample scenario. The parameters utilized are transmuted into a logarithm. This was conducted to ensure data is normally distributed (Rjoub et al. 2021; Kirikaleli et al. 2020). Table 2 illustrates the data source, measurement, and unit of measurement. Also, the flow of analysis is depicted in Figure 1. The study economic function and econometric model are depicted in Equations 1 and 2:

$$GDP_t = f(CO_{2t}, URB_t, EC_t\ GCF_t) \quad [1]$$

$$GDP_t = \vartheta_0 + \vartheta_1 CO_{2t} + \vartheta_2 URB_t + \vartheta_3 EC_t\ + \vartheta_3 GCF_t + \varepsilon_t \quad [2]$$

In Equation 1, GDP, CO_2, GCF, and EC, and URB represent economic growth, CO_2 emissions, gross capital formation, energy consumption, and urbanization.

Table 2: Variables Units and Sources			
Variable	Description	Units	Sources
GDP	Economic Growth	GDP Per Capita Constant $US, 2010	WDI, (2021)
CO_2	Environmental Degradation	Metric Tonnes Per Capita	
GCF	Gross Capital Formation	% of GDP	
URB	Urbanization	Urban Population	
EC	Energy Use	Primary energy consumption is measured in terawatt-hours (TWh)	BP (2021)

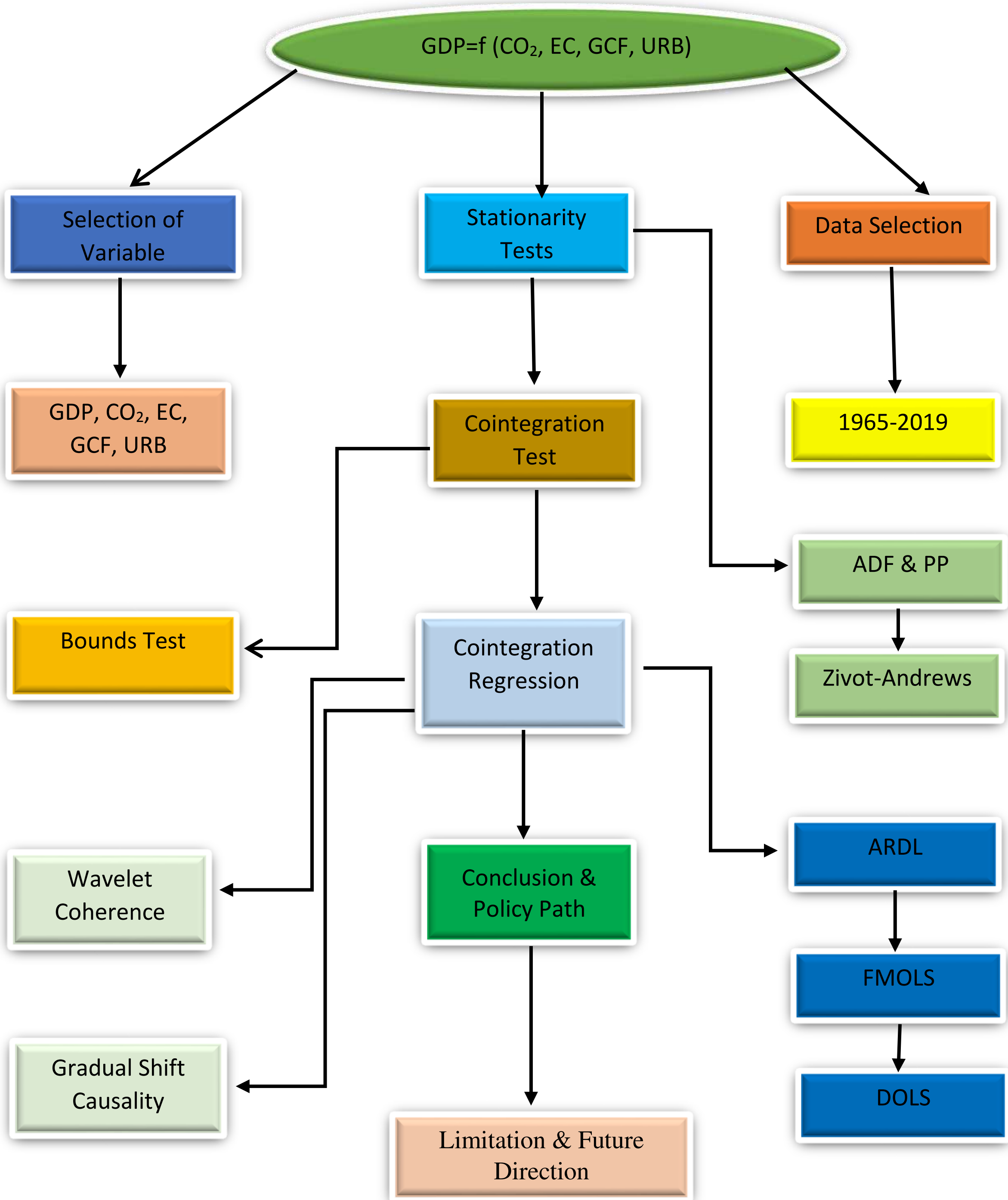


Figure 1: Analysis Flow Chart

3.2. Methodology

Analysis of correlation is used to verify the association of two-time series data. The correlation can be defined as follows:

$$\mathrm{Corr}\ (\mathrm{X,Y}) = \frac{Cov\ (X,Y)}{\sqrt{Var(X)Var(Y)}} \qquad (1)$$

where: the covariance between the two-time series (X,Y) is denoted as Cov(X,Y) while Var (X) and Var(Y) denotes the value of the two time series of X and Y respectively.

To achieve this purpose, ADF, PP, and Zivot and Andrews (ZA) unit root tests were employed to establish the order of integration. However, the ZA can capture both the stationarity property and structural break. This study employed the ARDL approach because this technique accommodates a limited number of observations (Ayobamiji & Kalmaz, 2020; Kirikkaleli et al., 2018). It is model is suitable for a model with different lags, and mixed order of integration. It is also beneficial because of the attributes of revealing coefficients in the short and long run simultaneously and solves the problem of autocorrelation. This makes the credibility of the formulated policy of this study to be effective. ARDL modeling is been defined in the equation below:

$$\begin{aligned} \Delta InGDP_t = \alpha_0 &+ \sum_{i=1}^{t} \alpha_1\, \Delta InGDP_{t-i} + \sum_{i=1}^{t} \alpha_2\, \Delta InC0_{2_{t-i}} + \sum_{i=1}^{t} \alpha_3\, \Delta InEN_{t-i} + \sum_{i=1}^{t} \alpha_4\, \Delta InGCF_{t-i} \\ &+ \sum_{i=1}^{t} \alpha_5\, \Delta InURB_{t-i} + \beta_1 InGDP_{t-1} + \beta_2 InCO_{2_{t-1}} + \beta_3 InEN_{t-1} + \beta_4 InGCF_{t-1} \\ &+ \beta_5 InURB_{t-1} + \rho ECT_{t-i} + \varepsilon_t \qquad (2) \end{aligned}$$

where: $\alpha_{i=5}$ and $\beta_{i=5}$ are the long and short-run parameters respectively, ρ denotes parameter for ECT_{t-i}, ε_t and Δ denotes the error term and first difference respectively and ECT_{t-i} represents the error correction term, which is the adjusted speed to long-run balance from short-run shock. The ARDL hypotheses are written below. The null hypothesis reiterates that there is no cointegration presence in the model while the alternate hypothesis affirms a contradictory view, which is the presence of cointegration.

$$\mathrm{H_o}: \alpha_0 = \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 \qquad (3)$$

$$\mathrm{H_l}: \alpha_0 \neq \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5 \qquad (4)$$

The testing procedure in the ARDL model is by comparing the F or T statistics calculated with the critical bound (lower and upper bound). Normality test, heteroscedasticity test, Ramsey RESET, and serial correlation are the diagnostic test was undertaken, to examine for BLUE. Model stability was checked employing the cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUM of squares). Furthermore, the long-run coefficients of the ARDL model were verified using the FMOLS and DOLS tests.

Wavelets coherence is employed to detect the time-frequency dependence of energy consumption, CO_2 emissions, urbanization, and gross capital formation on economic growth. Time-frequency dependence puts into account the changes over time and how the relationship varies from one frequency to another becomes essential and strategic in the formulation of policies (Mutascu, 2018; Alola & Kirikkaleli, 2019; Umar et al., 2020; Alola & Kirikkaleli, 2020). The Morlet wavelet function was employed since it brings balance between phase and amplitude. Morlet wavelet function is defined as follows:

$$w(n) = \pi^{-\frac{1}{4}} e^{-iwn} e^{-\frac{1}{2}n^2} \tag{5}$$

Note: non-dimensional frequency was used by w; i denotes $\sqrt{-1}$ p(n). Using the time and space, with n = 0,1, 2, 3……N-1, the time series continuous wavelet transformation (CWT) is defined as:

$$w_{k,f}(n) = \frac{1}{\sqrt{h}} w\left(\frac{n-k}{f}\right), \; k, f \in \mathbb{R}, f \neq 0 \tag{6}$$

where: k and f symbolize time and frequency respectively. CWT helps the cross wavelets analysis to interrelate between two variables (Kirikkaleli, 2019). The CWT equation is written below as follows:

$$\mathfrak{w}_p(k, f) = \int_{-\infty}^{\infty} p(n) \frac{1}{\sqrt{f}} w\left(\frac{\overline{n-k}}{f}\right) dn, \tag{7}$$

The local variance was revealed using the wavelet power spectrum (WPS). The equation defining the WPS is as follows:

$$WPS_p(k, f) = \left|W_p(k, f)\right|^2 \tag{8}$$

To examine the co-movement between two-time series, the wavelet coherence approach (WTC) was used, which is defined in the equation below:

$$R^2(k, f) = \frac{\left|S\left(f^{-1} W_{pj}(k, f)\right)\right|^2}{S\left(f^{-1}\left|W_p(k, f)\right|^2\right) S\left(f^{-1}\left|W_j(k, f)\right|^2\right)} \tag{9}$$

where: the smoothing operator to both time and scale with $0 \leq R^2(k,f) \leq 1$ is denoted as S. WTC can also detect the phase difference ϕ_{pq} of the two time series, it defined in this form:

$$\phi_{pq}(k, f) = \tan^{-1}\left(\frac{\mathrm{L}\left\{S\left(f^{-1} W_{pj}(k, f)\right)\right\}}{O\left\{S\left(f^{-1} W_{pj}(k, f)\right)\right\}}\right) \tag{10}$$

where: L denotes an imaginary operator while O stands for a real part operator.

Apart from the wavelet coherence approach, the Gradual-shift causality test developed by Nazlioglu et al. (2016) was utilized to establish the direction of causation between two variables. Nazlioglu et al. (2016) employed the Toda and Yamamoto (1995) and Fourier approximation, which captures the structural changes during the period of coverage (Kirikkaleli and Gokmenoglu, 2020; Gokmenoglu et al., 2019). This technique helps to overcome the inaccuracies and inconsistencies associated with the VAR model. Using the modified VAR model stated in the equation below:

$$y_t = \sigma(t) + \beta_1 y_{t-1} + \cdots + \beta_{p+dmax} y_{t-(p+dmax)} + \varepsilon_t \tag{11}$$

Where: y_t symbolizes variable used; σ symbolizes intercept; β symbolizes coefficient matrices; ε symbolizes the error term; t symbolizes time function. The Fourier approximation with cumulative frequencies is defined as:

$$\sigma(t) = \sigma_0 + \sum_{k=1}^{n} \gamma_{1k} \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} \gamma_{2k} \cos\left(\frac{2\pi kt}{T}\right) \quad (12)$$

Where: γ_{2k} and γ_{1k} measures the displacement and frequency amplitude respectively; the number of frequencies is denoted as n. Fourier Toda-Yamamoto causality with cumulative frequencies (CF) is defined as follows in:

$$y_t = \sigma_0 + \sum_{k=1}^{n} \gamma_{1k} \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} \gamma_{2k} \cos\left(\frac{2\pi kt}{T}\right) + \beta_1 y_{t-1} + \cdots + \beta_{p+dmax} y_{t-(p+dmax)} + \varepsilon_t \quad (13)$$

Where: approximation frequency is symbolized as k. For the Fourier Toda-Yamamoto causality with single frequencies, single-frequency components are defined in Equation (9) as follows:

$$\sigma(t) = \sigma_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) \quad (14)$$

The Fourier Toda-Yamamoto causality with single frequencies (SF) is defined as follows:

$$y_t = \sigma_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \beta_1 y_{t-1} + \cdots + \beta_{p+d} y_{t-(p+d)} + \varepsilon_t \quad (15)$$

4. FINDINGS AND DISCUSSION

The present paper aims to examine the connection between CO_2 emissions (CO_2) and economic growth (GDP) as well as the role of urbanization (URB), gross capital formation (GCF), and energy usage (EC) in South Korea between 1965 and 2018. Figure 2 (correlation box) depicts the correlation among the parameters. The outcomes of the correlation show that all the variables have a strong correlation with each other with the exemption of GCF with has a weak correlation with other indicators. Consequently, the elementary summary statistical characteristics that report the measure of central tendencies and dispersion outlined in Table 3 show that urbanization reveals the highest average followed by economic growth, energy use, and the least gross capital formation. All series shows negative skewness with light tail and the kurtosis revealed that data are normally distributed with the exemption of GCF. Furthermore, the study utilized the aforementioned methods to tests the stationarity features of the data and the outcomes show that the parameters are integrated at mixed order i.e. I(I) and I(0) as depicted in Tables 4 and 5, respectively.

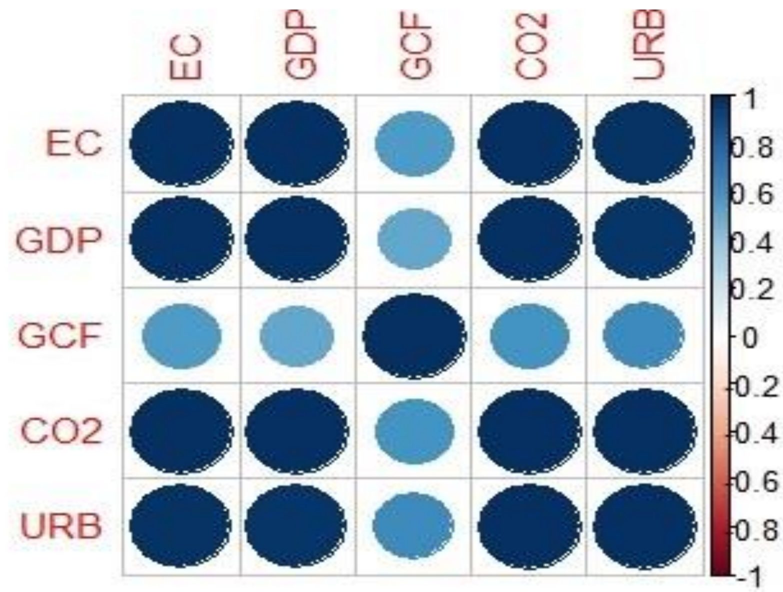


Figure 2: Correlation between GDP, URB, EC, GCF and CO_2

Table 3: Descriptive Statistics					
	GDP	CO_2	EC	GCF	URB
Mean	3.899157	0.722277	1.905183	1.494485	7.435024
Median	3.990954	0.812789	2.046541	1.508928	7.520742
Maximum	4.457504	1.141450	2.389607	1.615256	7.624351
Minimum	3.062850	-0.059921	0.968732	1.169181	6.967840
Std. Dev.	0.433817	0.337479	0.434017	0.075982	0.196133
Skewness	-0.388375	-0.696901	-0.558883	-1.695635	-0.921605
Kurtosis	1.819464	2.317733	1.986679	7.925874	2.583351
Jarque-Bera	4.576475	5.518732	5.216344	81.96133	8.183577
Probability	0.101445	0.063332	0.073669	0.000000	0.016709
Obs	55	55	55	55	55

Table 4: Traditional Unit root Tests			
ADF Unit Root Test			
	At Level I(0)	First Difference I(1)	Decision
	Intercept & Trend	Intercept & Trend	
GDP	0.3979	-0.9324*	I(1)
CO_2	-0.9710	-8.0537*	I(1)

EC	-0.5678	-7.0742*	I(1)
GCF	-4.7370*	-6..3073	I(0),I(1)
Urban	-4.9187*	-2.1810	I(0)
PP Unit root Test			
GDP	0.6869	-6.9458*	I(1)
CO_2	-0.9463	-8.0591*	I(1)
EC	-0.5908	-7.0742	I(1)
GCF	-4.7149*	-15.3632	I(0),I(1)
URB	-4.0221**	-2.6810	I(0)
Note: 1% and 5% level of significance is illustrated by and ** correspondingly			

Table 5: ZA Unit root Test					
	At Level I(0)		First Difference I(1)		Decision
	Intercept & Trend	Break-Date	Intercept & Trend	Break-Date	
GDP	-2.8836	1994	-7.8407*	1983	I(1)
CO_2	-3.8751	1993	-8.6482*	1998	I(1)
EC	-4.2704	1991	-7.9482*	1984	I(1)
GCF	-6.4665*	1998	-7.0113*	1997	I(0),I(1)
URB	-5.2474**	1986	-5.7052*	1996	I(0),I(1)
Note: 1% and 5% level of significance is illustrated by and ** correspondingly					

After the stationarity characteristics of the series are affirmed, we proceed to the estimation of the ARDL framework which is reported in Table 6. The outcomes are presented in such a manner that the existence of a long-run association between the parameters are verified if the estimated value of the F-test is greater than the values of both limits (lower and upper bound). In this scenario, we accept fail to accept the null hypothesis of no cointegration. Nonetheless, if the F-statistics is less than the lower bound critical value, the alternative explanation of the presence of cointegration is dismissed. Although, if the F-stats breakdown between the two thresholds critical values, the finding is called conclusive.

We proceed to estimate the long-run and short-run association between variables of concern and findings are depicted in Table 7. Appropriate Lag selection is essential when applying the ARDL. Thus, we utilized the AIC criteria proposed by Akaike, (1987). As stated by Udemba et al. (2021) and Zhang e al. (2021), the AIC is preferred for selection lag due to its superior characteristics. The model goodness of fit is depicted by the R^2 (0.99) and Adj R^2 (0.98) respectively. The outcomes of the R^2 and Adj R^2 illustrate that 99% and 98% variation in GDP can be explained by URB, GCF, CO_2, and EC and the remaining percentage can be attributed to error. The adjustment speed is seen to facilitate long-term convergence between the parameters with a significant and negative error correction model coefficient (ECM). The outcome of the ECT is 0.22 which illustrates evidence of cointegration amongst the parameters, and this signifies the capability of the model to witness 22% speed of adjustment to verify the alignment to equilibrium in the long-run on GDP due to the effect of the regressors (URB, EC, CO_2, and GCF). The outcomes of the ARDL illustrate the different linkage between GDP and the regressors (URB, EC, CO_2, and GCF). For instance, there is proof of a negative linkage between GDP and CO_2 emissions in the short-run. This illustrates the increase in CO2 emissions will mitigate GDP which infers that an increase in CO_2 by 1% in the short-run is accompanied by a 0.28% decrease in GDP when other indicators are held constant. This result concurs with the findings shown by Lee's (2013) for G-20 nations and Udemba et al. (2021) for India. Furthermore, URB and EC exert a positive impact on GDP in the short run which illustrates that 1% in URB and EC will spur GDP by 1.92% and 0.23% respectively. This is a strong indicator that the intensity of energy and the populace are critical indicators in the growth of the South Korean economy. The industrial sector uses a momentous quantity of energy as one of the main contributors and generators of the South Korean economy, which in turn affects income positively. This outcome aligns with the results of Zhang et al. (2020) for Malaysia and Kirikaleli and Demet, (2020) for Turkey. Moreover, there is no evidence of interconnection between GCF and GDP in the short-run which aligns with the study of Olanrewaju et al. (2021) for Thailand and Zhang et al. (2021) for Malaysia.

In the long-run, there is evidence of a long-run association between GDP and CO_2 emissions which illustrates that a 0.15% increase in GDP is linked with a 1% surge in CO_2 emissions. This is not unexpected given that the South Korean economy is primarily an investment-oriented and manufacturing economy that relies heavily on the utilization of energy; nonetheless, a positive side of this is the potential to minimize CO_2 by shifting the energy-mix to include more renewable options such as wind and solar energy (renewables). Furthermore, urbanization influences economic growth positively in South Korea which is in the harmony with a positive linkage with GDP growth and urbanization. We see that a 1.92% increase in GDP growth is due to a 1% increase in the urban population. We make the claim based on the empirical revelation that the teaming growing population in South Korea is productive to her economic trajectory. Nevertheless, there is a necessity for cautiousness on the part of policymakers to match urban infrastructure and amenities in the rural area. This is to avoid the rush to urban cities given that most government officials develop urban areas more than a rural areas. Otherwise, the urban infrastructure might be overwhelmed and might impede economic growth in the long- run. We noticed that energy use improves GDP as we notice that a 0.23 % increase in GDP is due to an increase in energy use by a magnitude of 1%. This outcome gives credence to the energy-induce growth hypothesis which complies with the study of Nathaniel et al. (2020) for Nigeria and also in Pakistan by Shahbaz et al. (2012). This outcome implies that the South Korean economy is energy-driven and cannot embark on energy conservative strategies as such action will compromise economic growth.

Furthermore, various post estimation tests are conducted. The outcomes of the normality, serial correlation, heteroscedasticity, and Ramsey tests show that the model is well specified, and there is no serial correlation. Moreover, the outcomes of the CUSUM and CUSUMSQ depict in Figure 3a and 3b correspondingly exemplifies that the model is stable.

To confirm the outcomes of the ARDL long-run estimations, the current study utilized the FMOLS and DOLS which are portrayed in Table 8. The outcomes show that CO_2, EC, URB enhance GDP in the long-run while there is no evidence of significant interaction between GCF and GDP.

Table 6: Bound Test

Model	F-statistics	Cointegration	χ2 ARCH	χ2 RESET	χ2 Normality	χ2 LM
	5.61*	Yes	0.57 (0.56)	0.72 (0.47)	0.91 (0.63)	0.58 (0.44)
	10%		5%		1%	
	LB	UB	LB	UB	LB	UB
	2.26	3.35	2.62	3.79	3.41	4.68

Note * represent a 1% level of significance and LB and UB denotes lower bound and upper bound critical value.

Table 7: ARDL Long-run and Short-run Results

	Long-Run Result			Short-Run Result		
Variables	Coefficient	t-Statistic	Prob	Coefficient	t-Statistic	Prob
CO_2	0.1552**	2.0736	0.045	-0.2804*	-2.999	0.006
EC	0.2370**	2.1121	0.041	0.4142*	3.993	0.000
GCF	0.0486	1.1719	0.248	0.0695	1.691	0.103
URB	1.9218**	2.1331	0.039	4.0658*	2.789	0.010
ECT(-1)	-	-	-	-0.2273*	-4.030	0.000
R^2	0.99					
Adj R^2	0.98					

Note: 1% and 5% level of significance is illustrated by and ** correspondingly

Table 8: FMOLS and DOLS Outcomes

	FMOLS			DOLS		
Variable	Coefficient	t-Statistic	Prob.	Coefficient	t-Statistic	Prob.
CO_2	0.1443**	2.5057	0.017	0.2370**	2.4821	0.017
EC	0.2437*	2.8833	0.006	0.2332**	2.3277	0.025
GCF	0.0574	1.3338	0.185	0.0486	1.3770	0.177
URB	2.0115**	2.5782	0.014	1.9218**	2.5067	0.016
R^2	0.98			0.98		
Adj R^2	0.97			0.97		

Note: * and ** represents 1% and 5% level of significance respectively

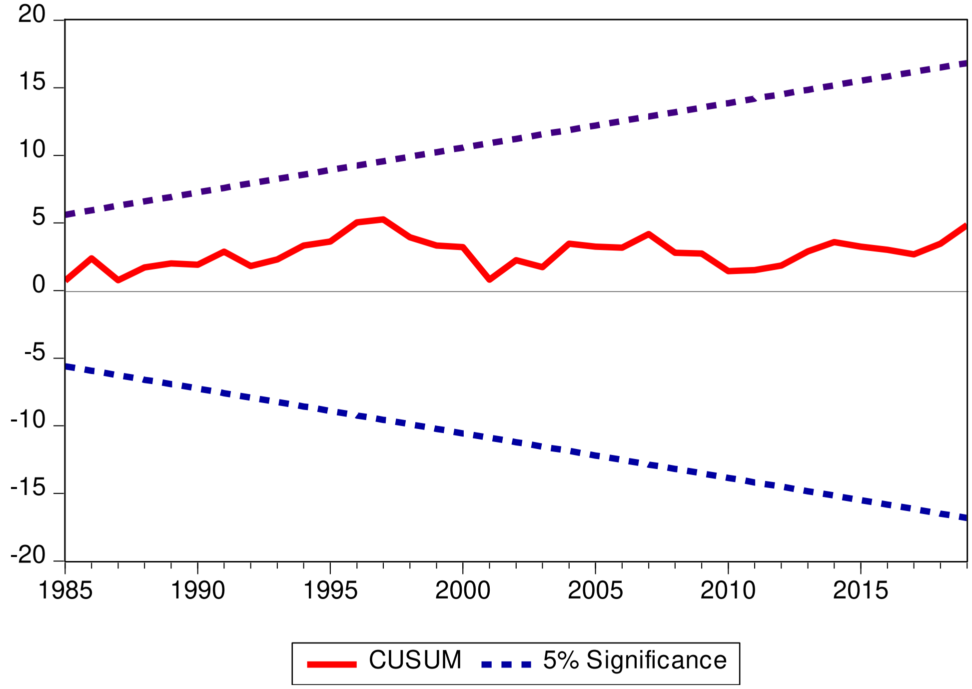


Figure 3a

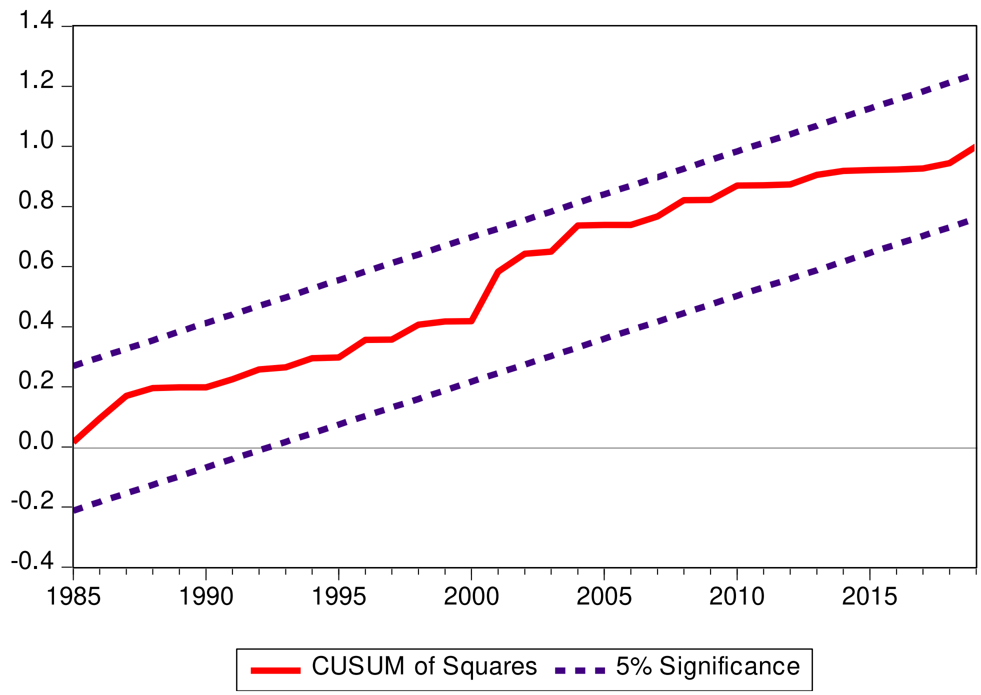


Figure 3b

The current research further utilizes the wavelet coherence (WTC) test to catch the causality and correlation between economic growth and the regressors. This method is crafted from physics to obtain formerly undetected information. Therefore, the research investigates the connection in the short, medium, and long-run between GDP and its regressors. The cone of influence (COI) is the white cone where discussion is carried out in the WTC. The thick black contour illustrates a level of significance based on simulations of Monte Carlo. In Figures 4a-4d, 0-4, 4-8, and 8-16 illustrate short, medium, and long term correspondingly. Moreover, the vertical and horizontal axis in the Figure depicts frequency and time respectively. The blue and yellow colors depict low and high dependence between the series. In-phase and out-of-phase connections are depicted by rightward and leftward arrows correspondingly. Moreover, the rightward-down (leftward-up) illustrates that the first variable lead (cause) the second parameter while the rightward-up (leftward-down) depicts that second parameter lead (cause) the first parameter. Figure 4a illustrates the WTC between GCF and GDP between 1965 and 2019. At different frequencies between 1970 and 2016, the arrows are rightward-up which shows the positive interconnection between the series with GCF leading. Figure 4b depicts the WTC between EN and GDP between 1965 and 2018 in South Korea. The majority of the arrows are rightward-up which illustrates a strong connection (dependency) at different frequencies with energy use leading. Figure 4c illustrates the WTC between URB and GDP in South Korea between 1965 and 2019. At different scales, from 1970 to 2016, the bulk of arrows are facing rightward-up which show positive association (dependency) at different frequencies. Furthermore, the rightward-up arrows show that URB lead (cause) GDP. Figure 4d illustrates the WTC between URB and GDP in South Korea between 1965 and 2019. At high and medium frequencies, from 1995 to 2003, the bulk of arrows are facing rightward-up which shows a positive association (dependency) between GDP and GCF. Furthermore, the rightward-up arrows show that GCF lead (cause) GDP. The outcomes from the wavelet coherence test comply with the results of DOLS, FMOLS, and ARDL.

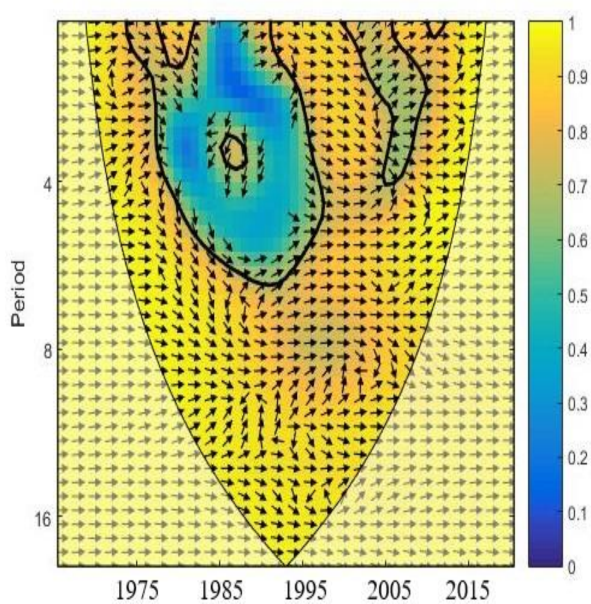


Fig 4a: WTC between GDP and CO_2

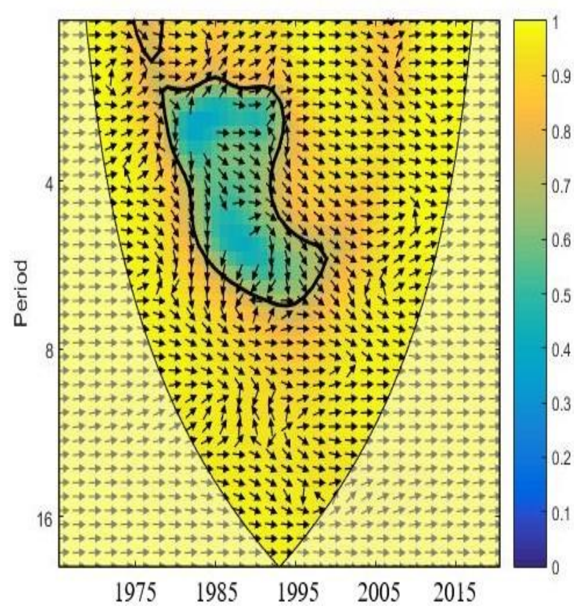
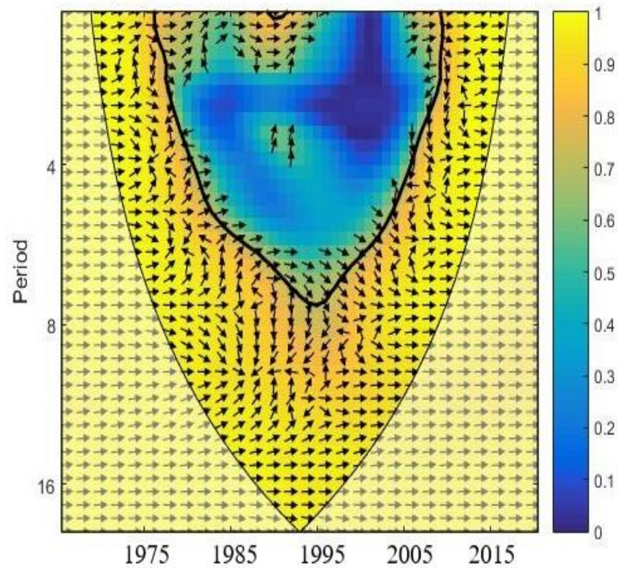


Fig 4b: WTC between GDP and EC



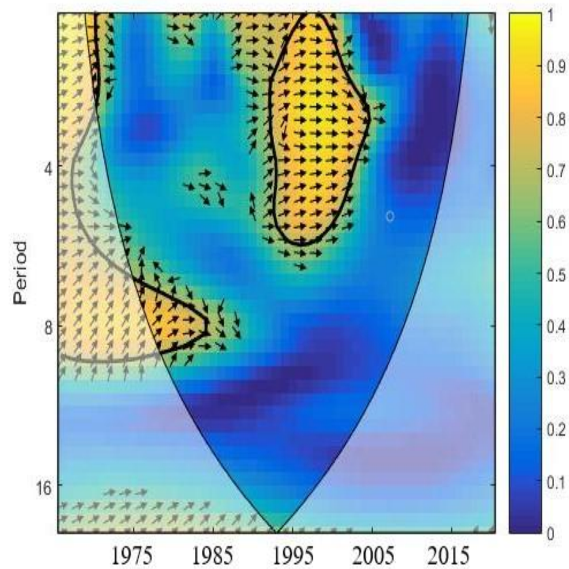


Fig 4c: WTC between GDP and URB

Fig 4d: WTC between GDP and GCF

To catch the causal interaction among the indicators, the Gradual shift method is applied and the results of this technique are depicted in Table 9. The outcomes from the Gradual causality test. The outcomes of the Gradual shift causality revealed; (i) one-way causality from EC to GDP at a significance level of 1%. This, therefore, suggests that South Korea's economic growth is not immune from development caused by fossil fuels. This is attributed to the fact that South Korea's economy heavily relies on production and manufacturing operations. This outcome corresponds to the findings of Ramakrishna & Rena (2013), and Udemba et al. (2021); (ii) unidirectional causality from CO_2 to GDP at a 1% level of significance which implies that CO_2 is a strong predictor of GDP in South Korea. In this regard, South-Korea policymakers should build policies in line with the nation's energy portfolio diversification. This finding is consistent with the findings of Zhang et al. (2021) for Malaysia, Adebayo (2020) for Indonesia, and Awosusi et al (2020) for MINT economies; (iii) one-way causality from GDP to URB at the significance level of 1% which illustrate that GDP can predict URB. This finding has consequences for South Korea's economic growth concerning rapid urbanization, where investment will be harnessed mainly to the vulnerable population with the promise of improvement in welfare. This outcome concurs with the findings of Awosusi et al (2020), Udemba et al. (2021), and Zhang et al. (2021).

Table 9: Gradual Shift Causality Test

Causality Path	Wald-stat	No of Fourier	P-Value	Decision
GDP→ EC	10.940	3	0.1412	Do not Reject Ho
EC → GDP	18.828*	3	0.0087	Reject Ho
GDP → URB	21.986*	1	0.0025	Reject Ho
URB→ GDP	5.868	1	0.5551	Do not Reject Ho

GDP → CO_2	10.721	2	0.1512	Do not Reject Ho
CO_2 → GDP	23.974*	2	0.0011	Reject Ho
GDP → GCF	10.721	2	0.1512	Do not Reject Ho
GCF → GDP	5.1177	2	0.6455	Do not Reject Ho
Note: 1%, 5% and 10% level of significance is illustrated by *, ** and ***correspondingly				

5. CONCLUSION AND POLICY DIRECTIONS

The current study adds to the previously existing by assessing the linkage between economic growth, CO_2 emissions, energy usage, urbanization, and gross capital formation. To accomplish the stated objectives, ARDL bounds testing, Gradual shift causality tests, as well as the novel wavelet coherence test, are utilized. The outcomes show a mix (significant and insignificant) of associations between economic growth and the regressors. The outcome of the bounds test reveals that all the indicators have long-run interconnection. Furthermore, the outcomes of the ARDL long-run and short-run estimations show that energy usage, urbanization, and CO_2 emissions enhance the economic performance of South Korea while gross capital formation exerts an insignificance impact on the economic performance of South Korea. Furthermore, we applied the novel wavelet test to capture the correlation and causal association between economic growth and the regressors. The findings of the wavelet analysis revealed a positive connection between economic growth and the regressors with the exemption of gross capital formation which has weak interconnection with economic performance. Further, the outcomes of the wavelet coherence test provide further support for the ARDL, FMOSL, and DOLS tests. The outcomes of the Gradual shift causality test provide intuition and credibility to the linkage among economic growth and urbanization, energy usage, gross capital formation, and CO_2 emissions.

The outcomes of this research have aided us to embrace the promotion of energy intensity diversification of South Korea. This could be done by the implementation of a more ambitious green energy initiative that will maintain the nation's economic momentum. The design and execution of successful policies to regulate South Korean energy and manufacturing sector practices will improve the nation's sustainable growth. This will continue to regulate the CO_2 pollution levels in the nation if the government sets emission restrictions on generating firms and factories. The threat of punitive action or high taxes on infringers of this policy will deter environmental pollution. Also, energy usage should be embraced via the incorporation of sustainable (renewable) energy sources including hydropower, oceanic, wind energy sources. Implementing the aforementioned policies will help to maintain sustainable economic development and South Korea's proven environmental performance. The outcome of this study would have a positive impact on neighbouring nations, who will be willing to take the steps suggested in this paper to strengthen their sustainable growth. Conclusively, this study has examined the nexus between energy use, urbanization, trade openness, and economic growth in South Korea using recent time-series data. Further studies can be conducted for the other emerging nations while considering asymmetric in the econometrics modelling or the use of micro disaggregated data. Furthermore, other studies can account for other growth drives not explore in this study.

Ethical Approval: This study follows all ethical practices during writing.
Consent to participate: Not Applicable
Consent to publish: Not Applicable

Authors Contribution: Madhy Nyota Mwamba and Tomiwa Sunday Adebayo designed the experiment and collect the dataset. The introduction and literature review sections are written by Tomiwa Sunday Adebayo, Gbenga Daniel Akinsola, and Abraham Ayobamiji Awosusi. Dervis Kirikkaleli and Abraham Ayobamiji Awosusi constructed the methodology section and empirical outcomes in the study. Tomiwa Sunday Adebayo and Gbenga Daniel Akinsola contributed to the interpretation of the outcomes. All the authors read and approved the final manuscript.

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Transparency: The authors confirms that the manuscript is an honest, accurate, and transparent account of the study was reported; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained.

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Figures

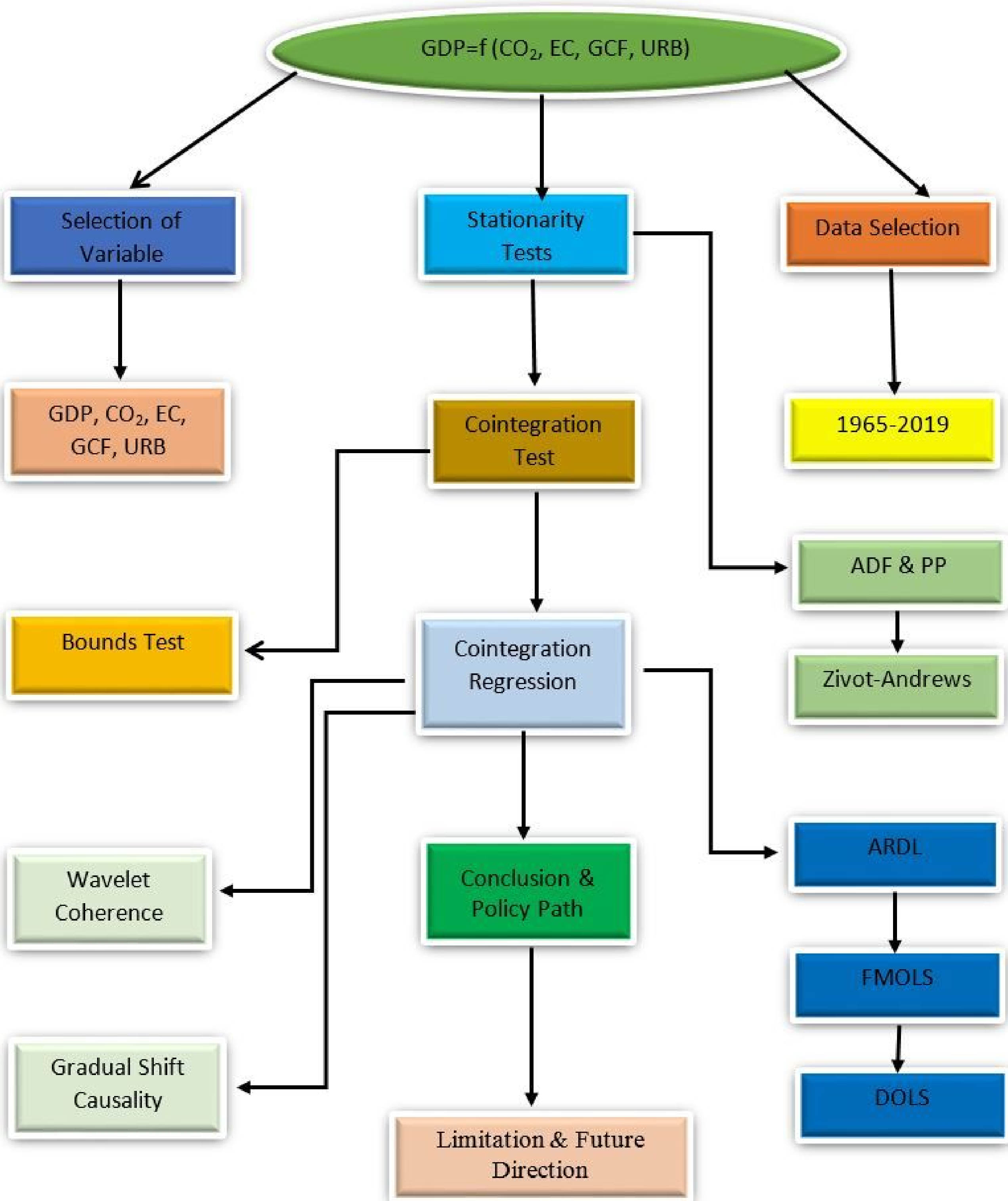

Figure 1

Analysis Flow Chart

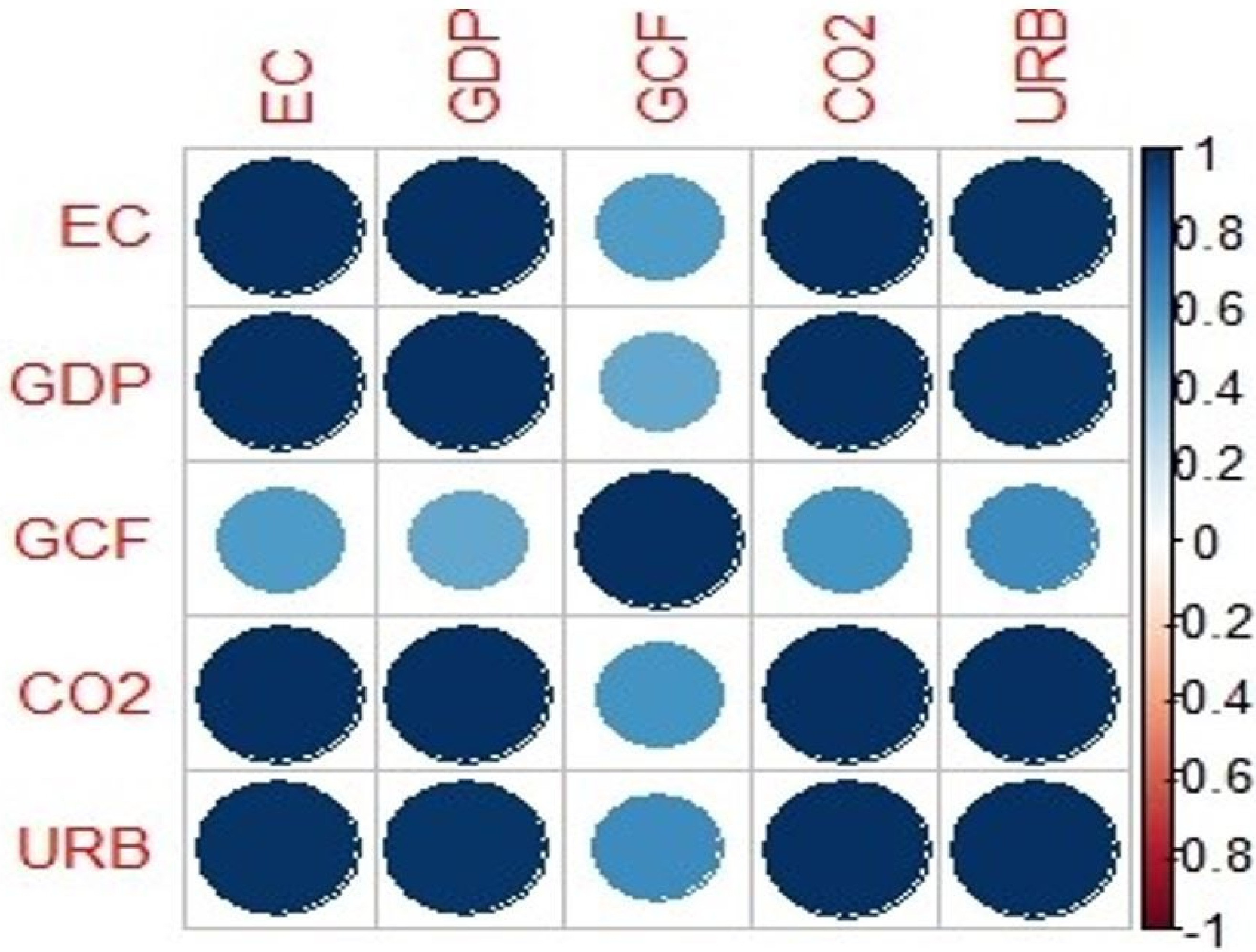

Figure 2

Correlation between GDP, URB, EC, GCF and CO2

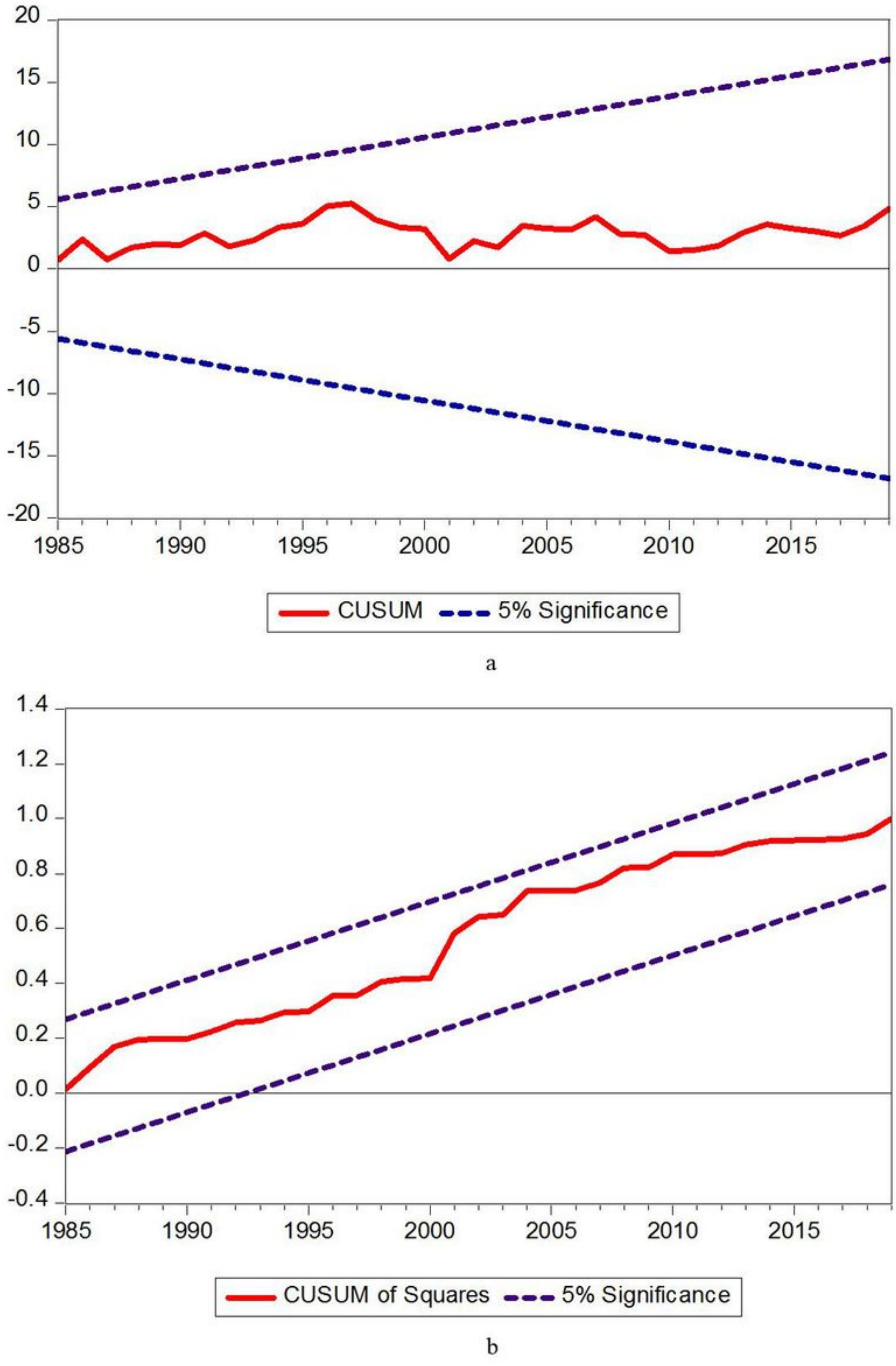

Figure 3

CUSUM and CUSUMSQ

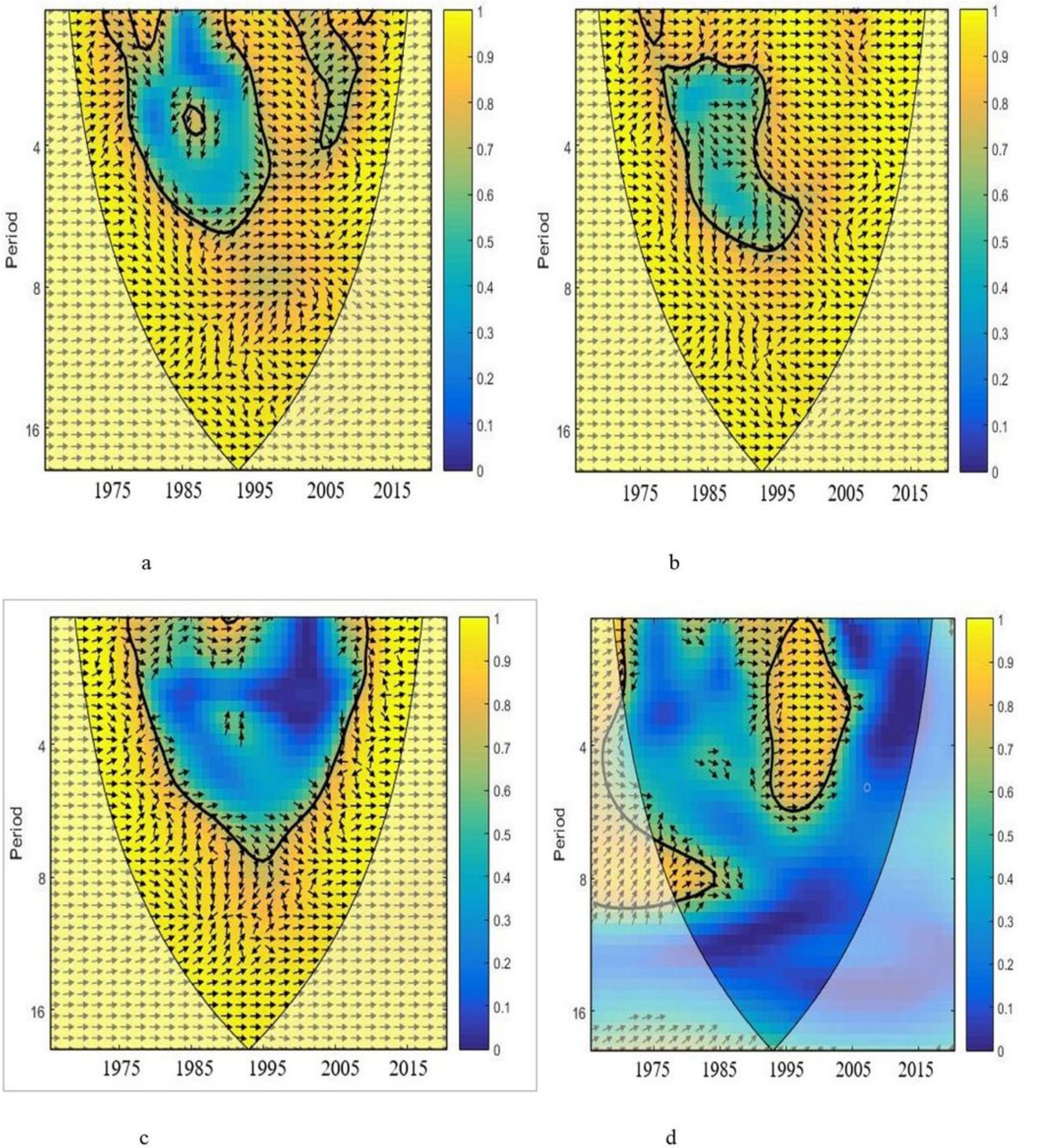

Figure 4

a: WTC between GDP and CO2. b: WTC between GDP and EC c: WTC between GDP and URB. d: WTC between GDP and GCF