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Impact of Economic Growth, Technological Innovation, and Globalization on Environmental Degradation in an Emerging Market

Ekonomik Büyümenin, Teknolojik İnovasyonun ve Küreselleşmenin Gelişmekte Olan Bir Pazarda Çevresel Bozulmaya Etkisi

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Bu güncel çalışma, küreselleşmenin, teknolojik yeniliğin, ekonomik büyümenin Güney Afrika'daki çevresel bozulma üzerindeki dinamik etkisinin, yenilikçi analizler kullanılarak araştırılmıştır. Bu araştırma, 1980 ve 2017 yılları arasındaki zaman serisi veriler icin dalgacık tabanlı teknikler uygulamıştır. Ampirik sonuçlar, CO2 emisyonu (CO2E) ile teknolojik yenilik, ekonomik büyüme ve küreselleşme arasında bir ilişki olduğunu kanıtlamaktadır. Ampirik bulgular, teknolojik yeniliğin, küreselleşmenin ve ekonomik büyümenin kısa ve orta vadede Güney Afrika'daki çevresel kaliteyi azalttığını göstermektedir. Ayrıca, Güney Afrika'da on yıllardır meydana gelen çevresel bozulmayı önlemek için yöneticiler tarafından koordine edilmiş politikalara sahip olmanın önemini vurgulamaktadır.

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A B S T R A C T

This current study reveals a new understanding of the dynamic impact of globalization, technological innovation, economic growth on environmental degradation in South Africa by utilizing innovative analyses. This research applied wavelet-based techniques for datasets between 1980 and 2017. The empirical outcomes establish proof of a connection between CO2 emissions (CO2E) and technological innovation, economic growth, and globalization over time and frequency. Additionally, from the viewpoint of frequency-domain, this paper shows impressive wavelet coherence and robust lead/lag interaction. The empirical findings indicate that technological innovation, globalization, and economic growth depreciate the level of environmental quality in South Africa in the short and medium-term. The findings highlight the importance of having coordinated policies by lawmakers and government officials to prevent environmental degradation that has taken place in South Africa for many decades.

1. Introduction

In 1992, 154 states signed and founded the United Nations Framework Convention on Climate Change (UNFCCC) in recognition of issues concerning the pressing need to safeguard the global climate. Since then, the UNFCCC parties have convened yearly meetings to decide what steps should be taken to regulate climate change and greenhouse

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gas emissions (GHGs). The Kyoto Protocol was the first initiative of the UNFCCC, which placed contractual commitments on advanced economies to reduce their GHGs. However, the Kyoto Protocol has never been a genuine universal deal, since the first and second amendments to the Kyoto Protocol contained only the EU and a handful of developed nations with obligatory pledges, and unfortunately the globe's biggest emitters, Canada, India, United States, among others, have not endorsed the Pacts. In contrast, by the Kyoto Protocol, more than 190 countries attended the United Nations Climate Change Conference (COP 21) held in Paris in 2015 and agreed on the Paris Agreement. According to the Paris Agreement, the parties have set a goal to limit global warming below 2°C compared to the pre-industrial levels by the year 2100, though it is later seen that it is unclear whether the participated countries will sanction the deal or not, for example, the United States. Despite some of the concerns, the Paris Agreement can be seen as a significant breakthrough in this matter, and the accomplishment of the goals in every region of the world is essential for maintaining and increasing the level of environmental quality (Cetin et al., 2021a).

Particularly for the case of the African region, South Africa is one of the biggest and fastest developing nations in the continent and the rest of the world. The economy of South Africa becomes one of Africa’s leading economies precisely following the start of South Africa’s democratic improvements in 1994. Additionally, according to the World Bank (2018), South Africa is one of the world's top producers of gold, platinum, and iron ore. The economy of South Africa has unique features that vary from other developing nations in Africa. These distinguishing characteristics comprise the economy which is the biggest CO2 emitter in Africa (responsible for 45% of total emission in the continent) and the 13th largest CO2 emitter globally (Enerdata, 2019). Moreover, the portion of energy created from coal is estimated as 77% of the overall potential electricity generation and retains the title of Africa's biggest coal user country (Enerdata, 2019). Achieving the target of maintaining global warming at that pace involves a massive reduction in the level of GHGs in the coming decades, and a critical question emerges as to how South Africa will reduce such environmental pollution. What about the linkage among the CO2 level and technological innovation, economic growth, and globalization for the case of South Africa? In order to find reasonable and significant answers to the research questions, previous research papers in the related literature are reviewed first. In the literature, some studies have summed up a positive association amongst globalization and CO2E (Ahmed et al. 2020) while on the contrary, some studies have concluded a negative relationship (Ahmed et al. 2020; Zafar, 2019). Moreover, some studies have found that technological advancements enhance the environmental quality (Yii & Geetha; 2017; Khan et al. 2019) while others have shown the opposite linkage among related variables (Ali et al., 2020).

Due to indecisiveness in the related literature, it seems necessary for additional investigation. In this paper, we shed light on the connection between the CO2E and three independent variables; technological innovation, globalization, and economic growth. A comprehensive investigation of the interconnection between the level of CO2E and technological innovation, economic development, and globalization is crucial to comprehend the connected research question: Do economic growth, technological innovation, and globalization impact the quality of the environment? This question warrants and require an exhaustive examination over the selected period. To the knowledge of the investigators, no previous investigation has widely examined the relationship between these variables, especially by using the data of South Africa as a case study. Thus, a thorough investigation is aimed to spot the causal connection amongst the CO2E level and the other economic variables. This study used quarterly data stretching between 1980 and 2017, which will aid to comprehend the interconnection between these economic indicators. Secondly, according to our knowledge on related subjects, most of the previously conducted investigations have examined such interconnections by using the time-domain techniques, including random effect, co-integration, OLS, CCR, ARDL, VECM, FMOLS, DOLS, etc. which, retrain the information efficacy on policies on environment and capturing the interconnection premised on time-domain for these indicators. Hence, this paper utilized the approach of wavelet techniques that detect dynamic dependencies between the chosen variables at different frequencies and time periods. In recent times, more scholars have examined and performed wavelet techniques upon relevant subjects of renewable energy, environmental quality, CO2E, and technological, financial, and economic developments and risks (Ali et al. 2020; Arain et al. 2020; Adebayo et al. 2020; Batool et al. 2018; Guan et al. 2020; Kondoz et al. 2021). Moreover, the Morlet wavelet is the particular technique utilized because it “offers information on the phase and amplitude which is crucial to examine dissimilar time-series synchronization” (Arain et al. 2020) that uncover the relationship among these selected economic datasets. The next segment delivers a discussion on the previous research papers in the related literature. In section 3, we presented the datasets and methods considered in this study. The next part reveals the empirical findings and the paper concludes with recommendations constructed in Section 5.

2. Literature Review

For over twenty years, human-related environmental pollution and disasters have become one of the most prominent global issues and concerns have arisen on how to act on environmental pollution reduction, trigger renewable energy consumption, and perform sustainable economic development. Notwithstanding expanded awareness and commitment to global environmental and climate change, the world is as yet not seeing an exceptional reduction in CO2E. More recently, various research papers have explored the association among economic growth, technological innovation, globalization, and the level of environmental condition (Kalmaz & Kirikkaleli, 2019; Umar et al. 2020; Ahmed et al. 2020; Ali et al. 2020; Awosusi et al. 2020; Saint et al. 2020; Shahbaz et al. 2020; Akinsola & Adebayo 2021; Wang et al. 2020; Arain et al. 2020; Yii & Geetha 2017; Dong et al. 2018). However, the results of these previous researches are mixed and there is no general consensus. For instance, Rafindadi et al (2019) studied the determining factors of CO2E for the case of South Africa by using over 40 years of the dataset (from 1971 to 2014). The investigators utilized FMOLS, CRR, and ECM estimators to establish these dynamics. The empirical results support the Environmental Kuznets Curve (EKC) hypothesis which labels the connection amongst economic growth and ecological quality, and the impulse response assessment shows that globalization can predict 72.52% variation in the CO2E in the long period. Furthermore, they showed a bidirectional causality effect amongst globalization and economic growth. Ahmed et al. (2020) examined the effect of globalization on environmental quality for the case of Malaysia by employing the ARDL, Bayer & Hanck cointegration, and causality techniques and their outcomes revealed that "globalization, energy usage, and economic growth exert a positive impact on ecological footprint while financial development and the population density enhance environmental quality. Moreover, there is a presence of bi-directional causality among economic development and energy expenditure in both short- and long- term". Moreover, Ali et al. (2020) examined the linkage of energy usage, economic growth, renewable energy, and the level of environmental quality in Malaysia between 1971 and 2019 by employing the wavelet techniques and found positive co-movement between energy consumption and CO2E. They stated that "the use of renewable energy decreases CO2E at different frequencies.". Khan et al. (2019) examined the effect of energy usage, globalization, technological advancement, and ecological corruption in Pakistan in the range of 1971 and 2016. They considered the CO2E variable as a proxy to ecological corruption and employed the dynamic ARDL method to explore dynamics within the variables. The outcomes reveal that energy usage, financial advancement, globalization, and trade openness exert a positive influence on CO2E while technological advancements and urbanization improve the level of ecological quality.

Fan & Hossain (2018) studied the effect of technological innovation and trade openness on CO2E in India and China from 1974 to 2014. The investigators used the ARDL technique to investigate this interaction and the empirical findings showed that trade openness harms the quality of the ecology though there was no significant connection found between the CO2 emissions and technological advancements. Additionally, Dong et al. (2018) investigated the relation among renewable energy usage and environmental quality in China between the years 1965 and 2016 using ARDL methodology. Dong et al. (2018) concluded that renewable energy and gas usage enhance the level of ecological quality. Later, ¬¬Umar et al. (2020) examined the linkage of financial development, technological innovation, and the CO2 emissions in China from 1971 to 2018 by employing Bayer & Hanck cointegration and wavelet coherence techniques. The empirical results show that economic advancements and technological innovation impede environmental quality whereas advancements in financial activities improve it. Cetin et al. (2018) proposed to capture the effect of urbanization on CO2E in Turkey while taking into account economic growth and energy consumption. The findings of Cetin et al. (2018) reported that urbanization is important factor to predict CO2E in Turkey. Ozturk et al. (2021b) recently explored the asymmetric effect of income inequality on CO2E in Turkey and their findings report that in the long run, CO2E in Turkey was increased by income inequality. According to the outcomes of Cetin et al. (2018b), CO2E is caused by trade openness, economic growth, energy consumption, and financial development in Turkey

Balsalobre-Lorente et al. (2018) examined the dependencies among renewable energy, technological advancements, and the quality of the environment by taking a dataset between 1985 and 2016 into account and considering 5 European Union states and showed significant evidence of dependency between real growth and CO2E. They also pointed out that sustainable energy and technological advancement improve ecological quality while trade openness decays the ecological quality. Kalmaz & Kirikkaleli (2019) utilized the ARDL-based bounds and wavelet methodologies to investigate the effects of real growth, urbanization and trade openness on the degradation of the environmental quality in Turkey. They showed that "economic growth, urbanization, and energy consumption exerts a positive impact on CO2E.". By employing the panel FMOLS, DOLS, and D-H causality methodologies and focusing on the top 10 electric consumer nations, Rahman (2020) stated that "economic development and electricity consumption worsens the quality of the environment whereas the globalization improves the environmental quality. Also, the one-way causal linkage is detected that runs from real growth to electricity use and from globalization to CO2E". Arain et al. (2020) researched the causal relations between environmental quality and renewable energy, economic development, foreign direct investment (FDI) in China using a dataset stretching between 1979 and 2017. To establish these dynamics, the researchers used wavelet tools and empirical outcomes to show connections among the parameters over time and frequency. Arain et al. (2020) concluded that "both in the short- and long-run, the consumption of renewable energy and the FDI inflows reduce the quality of ecological state, while renewable energy usage increases the quality of the environment.". For the case of the United States, by using the wavelet analysis technique Mishra (2019) stated that "it has been shown significant causal effects from transportation services, economic growth and tourist arrivals to the CO2E level between 2001 and 2017". Later, a more extended study by Khochiani & Nademi (2020) examined the wavelet coherence-based dependency among economic development, energy usage, and environmental corruption for the cases of the United States, China, and India. The outcomes show that in the short term, there is significant evidence of positive interconnectedness among the CO2E level and economic development. However, the co-movement among the selected variables was not significantly clear. Alola & Kirikkaleli (2019) explored the co-movements and causal linkages among the level of CO2E and the use of renewable energy, healthcare, and immigration in the United States using wavelet methodology, Toda-Yamamoto causality test, and gradual shift approaches. Alola & Kirikkaleli (2019) stated that "the results reveal feedback causal relationship among the level of CO2E and the use of renewable energy while a positive interconnection is detected between the CO2E level and healthcare and immigration in the short term.".

Table 1. Summary of related studies

Authors(s)	Time-Frame	Nation(s)	Variable(s)	Technique(s)	Finding(s)
Yii & Geetha (2017)	1971-2013	Malaysia	TECHI, CO_2E	VECM Granger causality	TECHI → CO_2 (-)
Balsalobre-Lorente et al. (2018)	1985-2016	5 European Union	GDP, GDP_2, TI, REN, CO_2E	ARDL	N-shaped GDP→ CO_2E (+) TECHI → CO_2E (-) REN→ CO_2E (-)
Fan & Hossain (2018)	1974-2014	China	GDP, TO, TECHI, CO_2E	ARDL	TO→ CO_2E (+) TECHI ≠ CO_2E
Dong et al. (2018)	1990-2014.	128 economies	GDP, POP, REN, CO_2E	CCEMG, FMOLS, D-H Causality	GDP→ CO_2E (+) POP→ CO_2E (-) REN→ CO_2E (+) REN→ CO_2E
Kalmaz & Kirikkaleli (2019)	1960-2016	Turkey	GDP, EN, TO, URB, CO_2E	FMOLS, DOLS, ARDL, Wavelet Coherence	GDP→ CO_2E (+) URB→ CO_2E (+) EN→ CO_2E (+)
Khan et al. (2019)	1971-2016	Pakistan	GDP, GLOEI, TECHI, URB, , EN, CO_2E	Dynamic ARDL	GDP→ CO_2E (+) GLOEI → CO_2E (-) EN→ CO_2E (+) TECHI → CO_2E (-) URB→ CO_2E (-)
Zafar (2019)	1990-2014	OECD nations	GDP, GLOEI, EN, CO_2E	CUP-FM, CUP-BC	EN→ CO_2E (+) GLOEI → CO_2E (-) FD→ CO_2E (-) GDP→ CO_2E (+) GDP^2→ CO_2E (-)
Rafindadi et al (2019)	1971-2014	South-Africa	GDP, GLOEI, GDP^2, CO_2E	T-Y Causality, Impulse Response, Maki coint. FMOLS, CRR, ECM	GLOEI → CO_2E (+) GDP→ CO_2E (+) GDP^2→ CO_2E (-) GDP↔ GLOEI
Mishra (2019)	2001-2017	USA	GDP, TS, CO_2E	Morlet's Wavelet, wavelet coherence	TS→ CO_2E (+) GDP→ CO_2E (+)
Umar et al. (2020)	1971-2018	China	GDP, FD, TECHI, CO_2E	Bayer-Hanck coint, wavelet coherence	GDP→ CO_2E (+) FD→ CO_2E (-) TECHI → CO_2E (+)
Ahmed et al. (2020)	1990-2016	Japan	GDP, FD, GLOEI, EN, EF	ARDL, NARDL	GDP→ EF (+) FD→ EF (-) $GLOEI^+$→ EF (-) $GLOEI^-$→ EF (-) GDP^2→ EF (-) EN→ EF (+)
Ali et al. (2020)	1971-2019	Malaysia	GDP, REN, EN, CO_2E	Wavelet tools	GDP→ CO_2E (+) REN→ CO_2E (-)

Table 1. Continued

Saint et al. (2020)	1970-2014	Turkey	GDP, GLOEI, ELEC, CO_2E	Bayer & Hanck coint, ARDL, T-Y Granger causality	GLOEI ≠ CO_2E EN→ CO_2E (+) GDP→ CO_2E (+) EN→ CO_2E GDP→ CO_2E
Shahbaz et al. (2020)	1984-2018	China	GDP, EXP, EN, TECHI, CO_2E	BARDL	GDP→ CO_2E (+) GDP^2→ CO_2E (-) EXP→ CO_2E (+) EN→ CO_2E (+) TECHI → CO_2E (-)
Ali et al. (2020)	1985-2012	Malaysia	GDP, FD, EN, CO_2E	VECM	GDP→ CO_2E (-) TECHI ≠ CO_2E GDP ↔ CO_2E TECHI ↔ CO_2E
Wang et al. (2020)	1990-2017	N-11 economies	GDP, FD, TECHI, CO_2E	Westerlund Cointegration, CCEMG	GDP→ CO_2E (+) FD→ CO_2E (+) TECHI → CO_2E (-)
Arain et al. (2020)	1979-2017	China	FDI, REN, GDP, CO_2E	Wavelet tools	FDI→ CO_2E (+) REN→ CO_2E (+)
Adebayo (2021)	1971-2016	Thailand	GDP, GDP2, EN, TO, CO_2E	ARDL, FMOLS, DOLS, Wavelet Coherence	GDP→ CO_2E (+) GDP^2→ CO_2E (+) TO→ CO_2E (-)
Khochiani & Nademi (2020)	1971-2013	United States, China, and India	GDP, EN, CO_2E	Wavelet Coherence	GDP→ CO_2E (+) EN→ CO_2E (+)

Note: CO_2E: Carbon emissions, TO: trade openness, TECHI: Technological Innovation, ARDL: Autoregressive distributed lag, EN: Energy Consumption, FD: Financial development, EXP: Exports, NARDL: Non-Linear ARDL, GLOEI: Globalization, REN: Renewable Energy, URB: Urbanization, TY: Toda-Yamamoto, ECM: Error Correction Model.

Over the years, numerous pieces of literature argued the linkages between the above-mentioned environment- and economic- indicators; yet, these discoveries are inconclusive, which diverges considering dissimilar methods, time-series data, the duration for different regions around the world.

3. Data and Methodology

This research tends to investigate the time-frequency causal relationship of globalization (GLOEI), economic growth (GDP), and technological innovation (TECHI) on the CO2 emissions (CO2E) in South Africa considering quarterly data from 1980Q1 to 2017Q4. Because of information inaccessibility and restricted sample size problem, we used the quadratic match-sum strategy in changing yearly information to quarterly information. This transformation strategy has been used by earlier investigations (Kirikkaleli, 2019; Gokmenoglu et al. 2019; Khan et al. 2020; Kirikkaleli & Athari, 2020; Shahbaz et al. 2020a), and it is useful to reduce point-to-point changes and changing seasonal errors through the transformation of low to high-recurrence information. Moreover, all of the selected time series are changed into their normal logarithm to ensure normality (Kirikkaleli & Kalmaz, 2020; Arain et al. 2020; Guan et al. 2020; Umar et al. 2020; Adebayo, 2020a). In this examination, the CO2E is considered as a dependent variable and the independent variables are GLO, TECHI, and GDPPC. Table 2 shows the data and their sources and measurement of the selected data.

Table 2. Data Source and Description

Variable	Description	Units	Sources
CO_2E	CO_2 Emissions	Metric tons per capita	WDI (2020)
GDPPC	GDP Per Capita	Constant US Dollars, 2010	
TECHI	Technological Innovation	Measured from both resident and non-resident patent applications	
GLOEI	Economic Globalization Index	Index Based on FDI, trade and portfolio investment	Gygli, et al., (2019): Revised KOF globalization Index.

Although some traditional unit-root tests can be performed for stationarity analysis of the variables, such unit root tests are excluded from this examination. The reason for this is because Kalmaz & Kirikkaleli (2019), Shabahz et al. (2019), Beton & Adebayo (2020), and Awosusi et al. (2020) asserted that "they yield ambiguity and erroneous outcomes due to the lack of structural break in the variables.”. Parallel to this statement, this paper considers the Zivot-Andrew unit root test that can detect structural breaks within the selected time series. Wavelet techniques bring major benefits which have the ability of spectral displaying of the cyclic arrays and trends, as well as the ability to perform for non-stationary time series. Moreover, the other methodological sections of the wavelets, such as the wavelet coherence (WTC) and continuous wavelet transform (CWT) deliver additional spontaneous apprehension into the dynamic dependencies of chosen time series variables by identifying reactions, in short, medium, and long-term, co-movements and lead/lag variables. The wavelet technique also enables us to monitor the shocks and breaks within the time series without having false outcomes (Si, Liu, & Kong, 2019). Parallel to this background knowledge, the South Africa case becomes more interesting for performing such research, and the empirical results can deliver significant policy implications, and the findings can be beneficial for policymakers and governors to find reasonable solutions for how to promote the production of green energy in South Africa by constructing and organizing complete economic growth and technological novelty rules.

4. Discussion of Data and Interpretations

This study investigates the time-frequency dependencies of the GDPPC rate, GLOEI, and TECHI on CO2E emissions (CO2E) in South Africa. ¬¬¬ The data description is depicted in Table 3. The findings revealed that all the variables conform to normality with the exception of TI as illustrated by the Jarque-Bera P-value. Along with this data characteristic, it is suitable to employ the wavelet technique, which is a non-linear estimator, and to analyze the dependencies between the selected time series variables (Guan et al. 2020). Figure 1 shows the outcomes of the correlation among CO2E, GDPPC, GLOEI and TECHI. The red and blue colours displayed in Figure 1 show negative and positive correlations respectively. The thick blue color and light blue colour denote positive and strong and weak correlation respectively while the thick red and light red shows the strong and weak correlation among these economic variables. Figure 2a, 2b, 2c and 2d displays the diagrams of CO2E, GDPPC, TECHI and GLO stretching between 1980 and 2017.

Table 3. Descriptive Statistics

Variable Code	CO_2E	GDPPC	GLOEI	TECHI
Mean	8.912	6524.065	53.852	7368.368
Median	8.758	6331.860	54.816	7283.500
Maximum	9.979	7582.697	70.640	10149.00
Minimum	7.728	5517.530	37.105	3140.000
Std. Dev.	0.638	696.8	13.719	1720.694
Skewness	0.155	0.232	-0.0189	-0.276521
Kurtosis	2.032	1.633	1.2074	3.059381
Jarque-Bera	1.634	3.301	5.0900	0.489855
Probability	0.442	0.192	0.078	0.782761

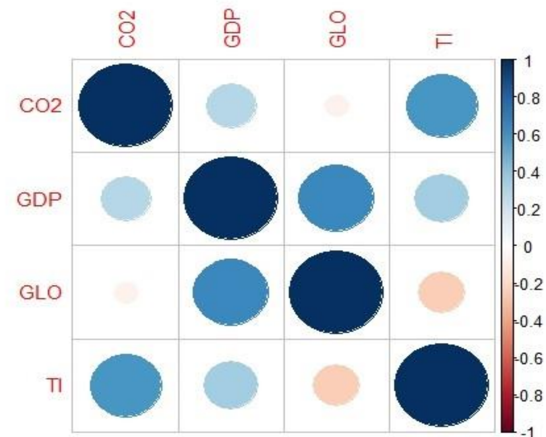

Figure 1. Correlation among CO_2E, GDPPC, GLOEI and TECHI

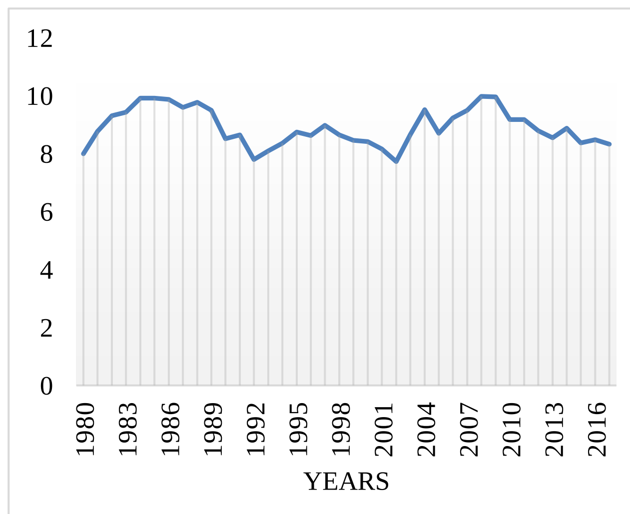

Figure 2a. CO_2E Emissions

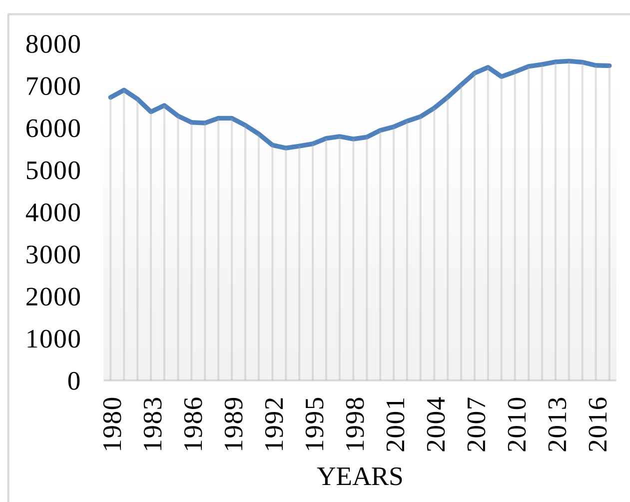

Figure 2b. Economic Growth

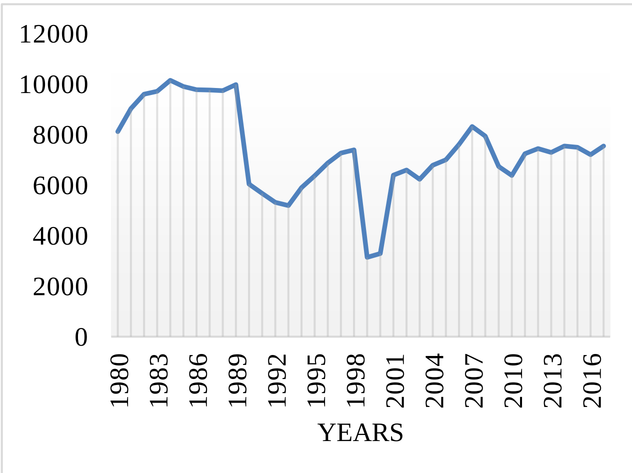

Figure 2c. Technological Innovation

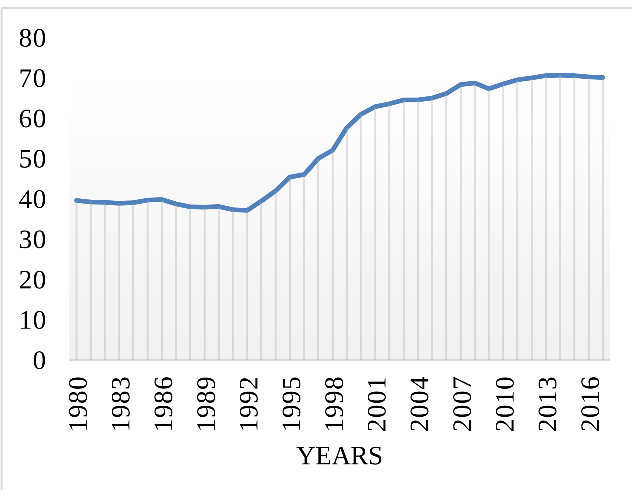

Figure 2d. Globalization

Based on our aims, we used unit root test with a single structural break detection within the series, so we performed the Zivot-Andrew test. Table 4 shows the summarized test results which demonstrate that the time series are non-stationary at level i.e. I (0). However, with the first difference i.e. I (1), all the variables are stationary with CO2E, GDPPC, GLOEI and TECHI having a single break of 1992Q2, 2008Q2, 1992Q2, and 2000Q2 respectively.

Table 4. Zivot-Andrew Unit Root Test

	At Level I (0)			
	CO_2E	GDPPC	GLOEI	TECHI
C&T	-4.00	-3,217	-3.538	-4.556
	[2003Q1]	[1989Q4]	[1996Q1]	[1990Q1]
	First Difference I (1)			
C&T	-5.491**	-5.539**	-5.586**	-5.728*
	[1992Q2]	[2008Q2]	[1992Q2]	[2000Q2]

Note: C&T represents constant and trend. *, ** and *** demonstrates significance level of 1%, 5% and 10%. The breakpoint is depicted inside [].

It is clear from the four chosen variables diagrams that the shape and movement are random and not predictable, revealing unexpected increase and drop in the selected time period. Subsequently, it will be difficult for the first sight detection of any visible periodic trend or cyclic. So, we utilized the wavelet transform to test the concealed patterns in selected datasets. Figures 3a, 3b, 3c, and 3d displays the Morlet wavelet transform for all the variables individually. The empirical findings from Figures 3a, 3b, 3c and 3d illustrate that in short time period, all the series exhibit high frequencies, although the time series becomes steady in the long time period. As stated by Vonesch et al. (2007), "the scale of decomposed energy is utilized in examining the short, medium and long-term dependencies amongst the variables. The energy in a time-series across scales is decomposed using MODWT and DWT. Four periods are used in describing the movements namely'; (i) short-term (D1 &D2); (ii) medium-term (D3 and D4); (iii) long-term (D5 and D6) and (iv) very long term (S6)." Accordingly, the empirical outcomes showed that most of the variations in time series exist in short phase, followed by the medium-run. Then, the variations convert to steady.

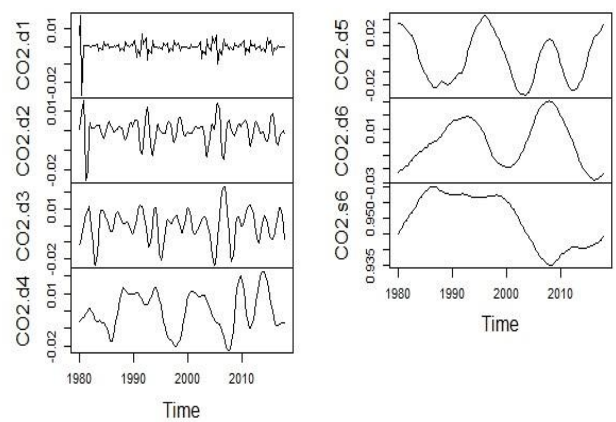

Figure 3a. CO_2E Emissions Wavelet Transform

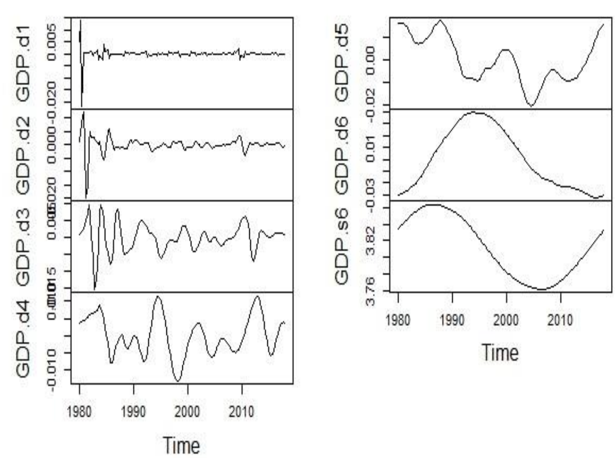

Figure 3b. GDPPC Wavelet Transform

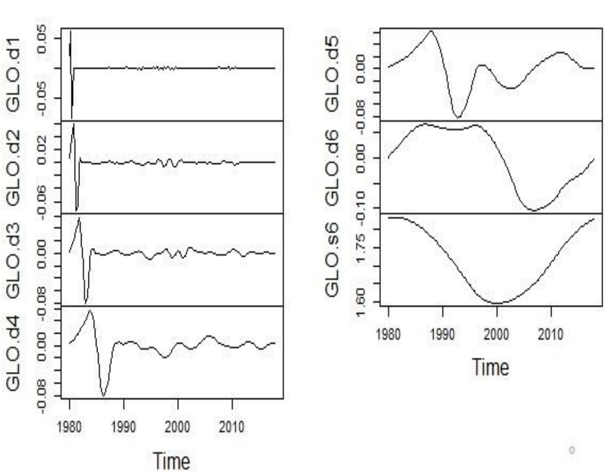

Figure 3c. Globalization Wavelet Transform

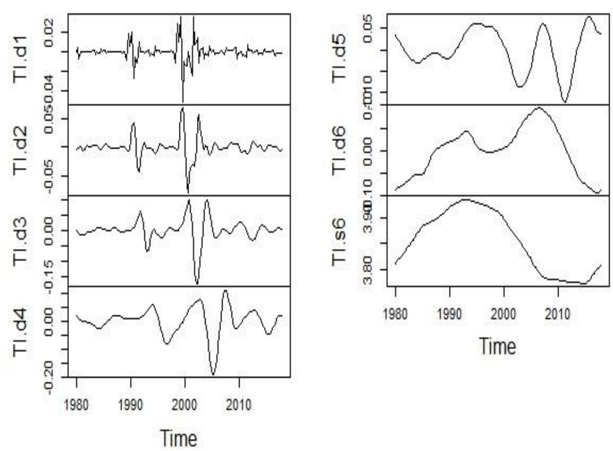

Figure 3d. Technological Innovation Wavelet Transform

Figures 4a, 4b, 4c and 4d give descriptions of the wavelet correlation between the CO2E and the independent variables. These figures exhibit the connection between CO2 and other variables at different levels. As stated in the study of Kondoz et al. (2021), "short, medium and long-run are illustrated by scale 1-2, 2-8 and 8-16 respectively. If the correlation value is close to 0, it represents no relationship between the variables; and if the correlation value is close to 1, it illustrates dependency between the two variables. Negative correlation implies opposite dependency.". The study is conducted for rising the scales of wavelet, which removes the inherent concealed facts in the data. Findings from the wavelet correlation reveal that; (i) there is weak correlation between CO2E and GLOEI; (ii) there is increasing positive correlation between CO2E and GDPPC at level 1-16; (iii) at scale 1-4, there is weak positive correlation between CO2E and TECHI, however, at level 4-8, there is strong and positive correlation between TECHI and CO2E. Therefore, we conclude that CO2E and GDPPC, and TECHI and CO2E depict evidence of interdependency while CO2E and GLOEI shows evidence of weak interdependence.

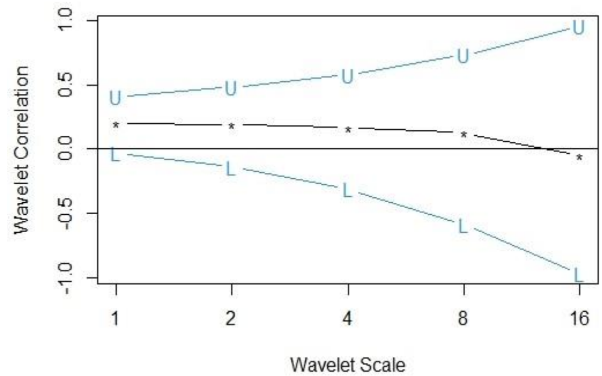

Figure 4a. WC Between CO_2E and GLOEI

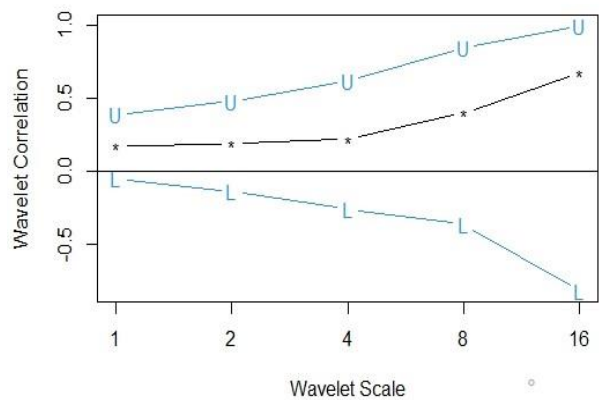

Figure 4b. WC Between. CO_2E and GDPPC

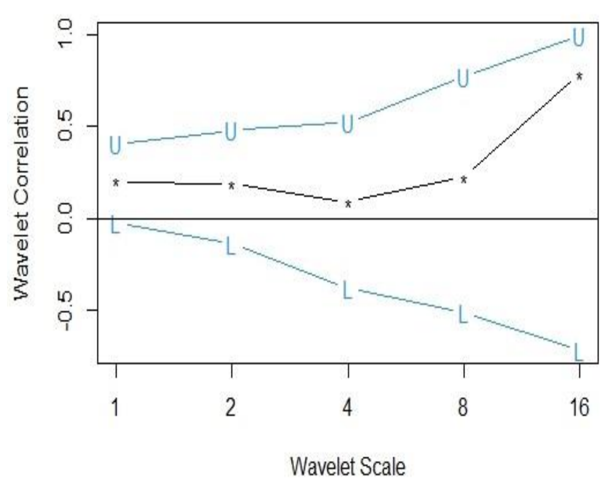

Figure 4c. WC Between CO_2E and TECHI

The WPS is utilized by the current study to catch the vulnerability of globalization, the consumption of renewable energy, economic development, technological advancements and CO2E in South Africa between 1980Q1 and 2017Q4. Figures 5a, 5b, 5c, and 5d depicts the WPS of CO2E, GLOEI, TECHI, and GDPPC correspondingly. We used MATLAB to find information for vulnerability in each variable. In light of the dataset covering the time span between 1980Q1 and 2017Q4, the study chooses 32 periods.

As Kondoz et al. (2021) stated, “the cone of influence (COI) is portrayed by the white cone-shaped line, which indicates a region where wavelet power is impacted while the thick dark shape signifies a critical degree of 5% determined by Monte Carlo simulations.”. This can be seen in the following figures. In Figures 5a-5d, CO2E, GLOEI, TECHI, and GDPPC are surrounded by the dark red region. These surrounded regions also indicate that the maximum-energy of the indicators are found in those areas. Figure 5a displays the WPS of CO2E in South Africa among the years 1980 and 2017. At medium and long term (medium and low frequencies), between 1985 and 2011, there is evidence of vulnerability in CO2E. Figure 5b reveals the outcome of the WPS of globalization between 1980 and 2017. At the medium frequency in 1998, there is vulnerability in globalization. Figure 5c shows the WPS of technological innovation between 1980 and 2017 in South Africa. There is significant volatility in technological innovation at medium and high frequencies between 1986 and 2011. Figure 5d portrays the WPS of CO2E from 1980 to 2017. There is proof of vulnerability in CO2E at medium and high frequencies between 1986 and 2011.

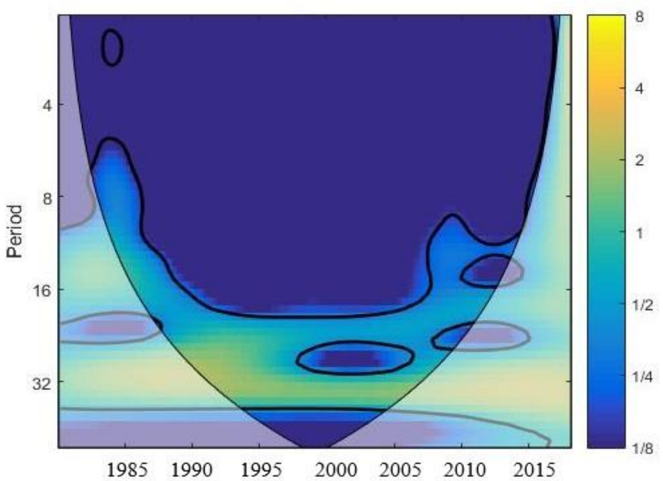

Figure 5a. WPS of Economic Growth

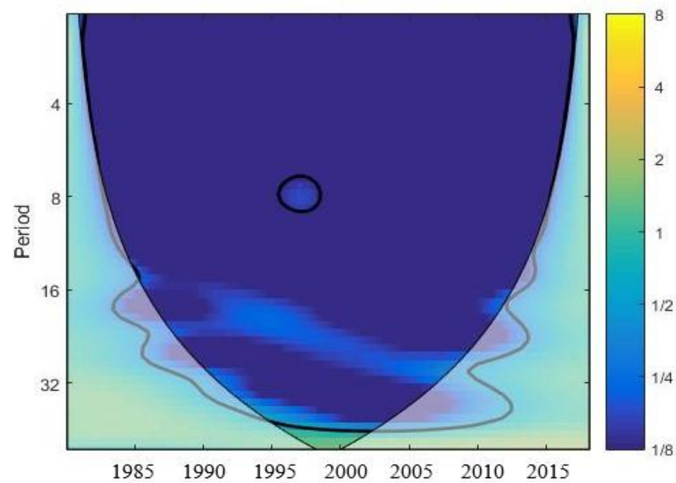

Figure 5b. WPS of Globalization

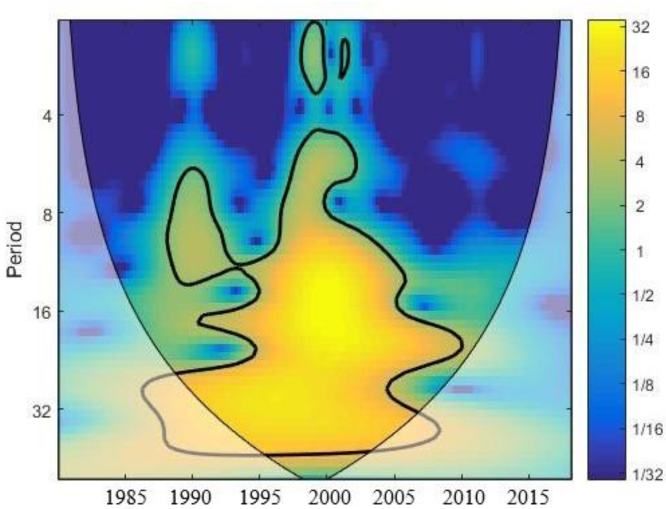

Figure 5c. WPS of Technological Innovation

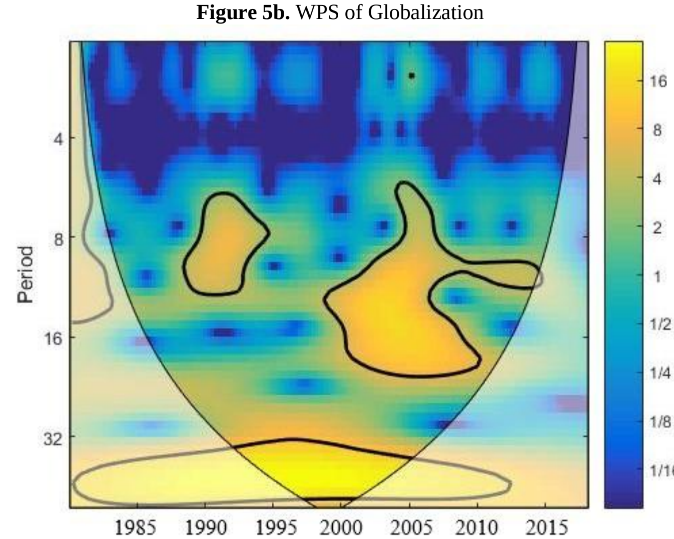

Figure 5d. WPS of CO_2E

After the vulnerability in CO2E, GDPPC, GLOEI and TECHI were found; we employed the wavelet coherence (WTC) to detect the time-frequency dependencies of (a) CO2E and GDPPC; (b) CO2E and GLOEI; and (c) CO2E and TECHI in South Africa between 1980 and 2017. Parallel to the statement in the study of Kondoz et al (2021) which is “the color scale at the right side in Figures 6a-6d, shows the strength of correlation / causality between the variables. The rightward and leftwards arrows illustrate in phase (positive correlation) and out of phase (negative correlation) between the two-time series. Moreover, the rightward-up (leftward-down) illustrates that the first series lead the second series while the leftward-up (rightward-down) demonstrates that the second series lead the first series. In addition, the warmer color (yellow) illustrates evidence of correlation whereas the cold color (blue) illustrates no correlation between the two-time series.". In the presented figures; figure 6a displays the WTC between CO2E and GDPPC in South Africa between 1980 and 2017. In the short term, from 1985 – 1987, we detected positive correlation among the variables with the GDPPC variable is leading. Moreover, we also detected a positive correlation between the variables at all frequencies from 1990 – 1992, 1994 and 1999 – 2000. Figure 6b reveals the WTC between CO2E and TECHI in South Africa from 1980 to 2017. At short and medium term, from 1990-1995, the variables are in phase with CO2E leading. Additionally, at high frequencies from 2009-2010, the variables are in phase with TECHI leading. Figure 6c portrays that the chosen variables are in phase at short and medium term between 1984 and 1987 with GLOEI leading. Hence, we concluded that increase in CO2E is followed by increase in TECHI and vice versa.

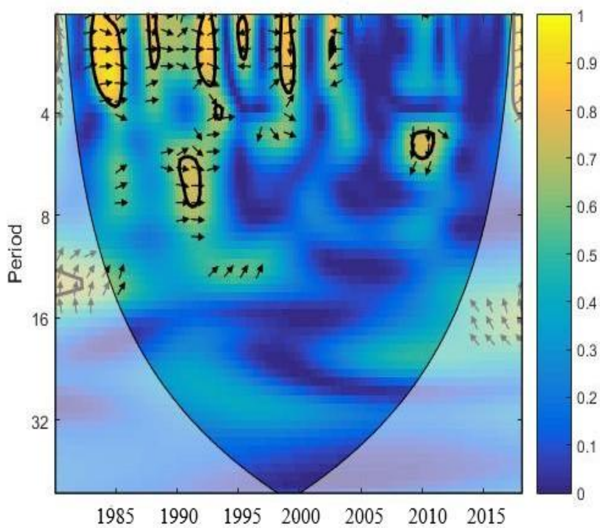

Figure 6a. WTC Between CO_2E and GDPPC

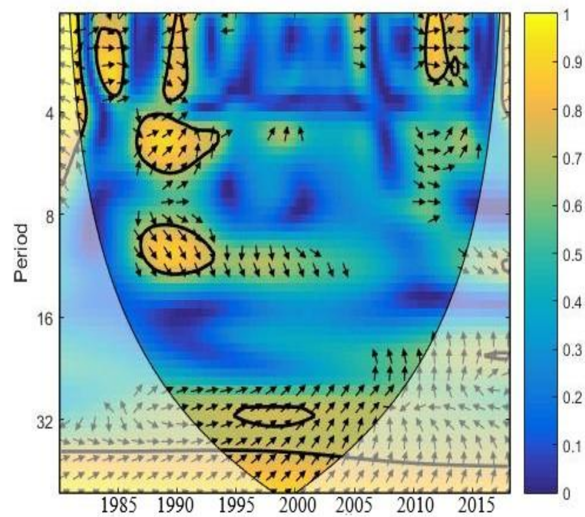

Figure 6b. WTC Between CO_2E and TECHI

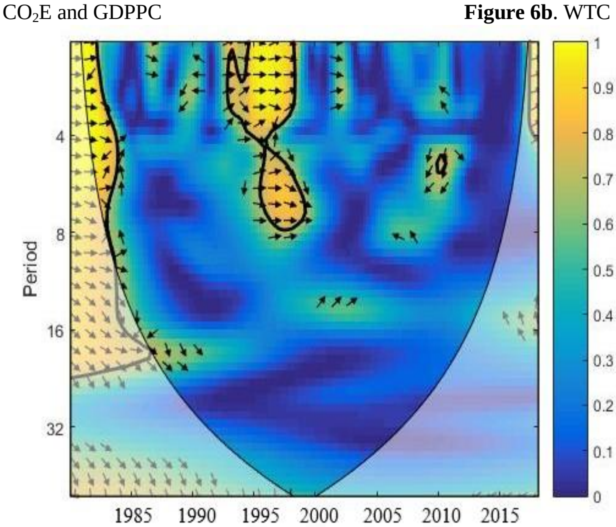

Figure 6c. WTC Between CO_2E and GLOEI

As stated in the study of Soylu et al. (2021), "partial wavelet coherence is indistinguishable from a partial correlation that expects to distinguish the outcomes of wavelet coherence between two time series in the wake of eliminating the impact of their common dependency. In the figures, the yellow tone portrays solid correlation while blue color displays weak or no coherence.". Figure 7a to 7f shows the outcomes of partial wavelet coherence analysis. Figure 7a represents that CO2E and GDPPC have solid co-movements between 1983-1986 and in 1990 in the short run. Figure 7b presents that the CO2E and GDPPC have significant co-movements in 1986, and between 1992-1993 and in 1999 in the short run. Figure 7c portrays significant coherence among CO2E and TECHI at 1983-1986 interval with influence of GLOEI not considered. Besides, in the other frequencies, strong coherence is also detected between 1987 and 1990. Figure 7d reveals solid coherence among CO2E and TECHI at high and medium frequencies between 1989 and 1991 with GDPPC influence cancelled. Figure 7e signifies the PWC between CO2E and GLOEI after annulling out TECHI. There is evidence of strong coherence in the short and medium term from 1995 to 2000 with the effect of TECHI cancelled. Figure 7f shows strong coherence between CO2E and GLOEI in high and medium frequencies between 1995 and 2000.

Figures 8a, 8b and 8c shows the multiple wavelet coherence (MWC) in South Africa between 1980 and 2017. Figure 8a illustrates that “in the short and medium-run, there is coherence between CO2E and GDPPC with the effect of TECHI considered between 1985 and 1993.”. Furthermore, at high frequency in 2000, 2005 and between 2012 and 2013, there is significant coherence among CO2E and GDPPC with the influence of TECHI considered. Figure 8b reveals that “at high and medium frequencies, there is strong co-movement between CO2E and TECHI between 1984 and 2000 with the effect of GLOEI considered.” In addition, at short and medium term there is sign of coherence between CO2E and TECHI from 2009 to 2012 with the influence of GLOEI considered. Finally, figure 8c displays “strong coherence among CO2E and GDPPC between 1983 and 2000 with the effect of GLOEI considered at high and medium frequencies.”.

5. Conclusion and Policy Path

This research explores the co-movements, between time and frequency framework, among CO2 emissions, technological innovation, economic growth, and globalization in South Africa by considering the data between 1980 and 2017. In order to explore these linkages, the current study employed novel techniques that are time-frequency methodologies such as wavelet correlation, wavelet transform, wavelet coherence, partial and multiple wavelet transformations. The paper also recognized the lead/lag association between the economic indicators.

The main contributing factor of this study to the literature is the application of the wavelet transformation techniques in order to evaluate joint time-frequency dependencies among the selected time series. The selected data displayed irregular patterns such as unpredicted increases and falls in a localized cyclical fashion. The wavelet transformation of these indicators displayed significant principal patterns, with time grasped in the smoothed elements and high-recurrence vacillations. In view of the outcomes, the majority of the discrepancy took place in the short run in all the series, which is trailed by the medium run. Nevertheless, as they go into the long run, the disparity becomes steady in all these indicators. Wavelet correlation analyses exposed interdependency across time among CO2E and economic growth, globalization, and technological innovation. The outcomes reveal a strong correlation at each level among economic development and CO2E level and between CO2E level and globalization. This implies that an increase is CO2E is associated with an increase in economic growth and technological innovation. Additionally, the correlation between CO2E and globalization is weak at each level. We also employed continuous wavelet transformation to identify vulnerability in these indicators at different frequencies. In addition, the wavelet coherence was employed to ascertain the co-movement between CO2E and technological innovation, economic growth, and, globalization in the short, medium, and long-term and the outcomes show that these indicators affect each other. The PWC and MWC additionally uncover the interconnections among the CO2E and economic growth, technological advancement and globalization. Concerning the PWC, the results demonstrate that canceling the impact of the third series did not affect the interconnection between the two series.

The discoveries from the MWC indicate that the connection between any two series is affected by the third series significantly in the short and medium-term. Thus, the paper concludes that economic growth, technological innovation and globalization harm the environmental quality in South Africa.

Towards the end, this research indicates that South Africa should follow policies that allow energy users to migrate towards green energy in order to enhance and maintain the sustainability of the environment. Moreover, lawmakers and government officials should take the requisite measures to diversify the total energy mix towards clean energy. In addition, diverse eco-innovation policies can be implemented with the goal of changing the manufacturing system from non-renewable energies to clean energy. In addition, we propose that government officials should utilize rational and efficient policy coordination to mitigate the possible costs of globalization on the environment. In view of the negative environmental effects of globalization, we recommend that lawmakers and government officials should not neglect the role of globalization in the carbon emissions trends when planning their extensive environmental policy agenda. Furthermore, we propose that lawmakers and government officials in South Africa should regard globalization as a core economic instrument in their environmental policy system to enhance their environmental quality. Environmentally sustainable technological innovation can also be introduced in the sense of collaborations and collaboration with high-income nations since technological advancements in certain nations are projected to accelerate high-quality growth in related nations. Finally, the empirical outcomes of this research not only enable governments and policymakers to create new policies to minimize environmental pollution, as indicated above but also progress previous studies through the use of wavelet tools.

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Appendices

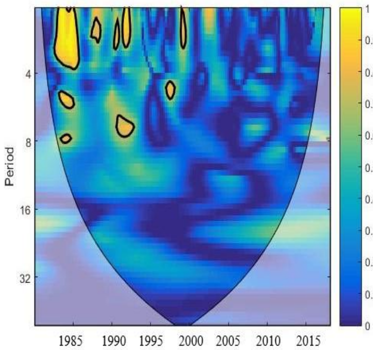

Figure 7a. PWC CO_2E - GDPPC - GLOEI

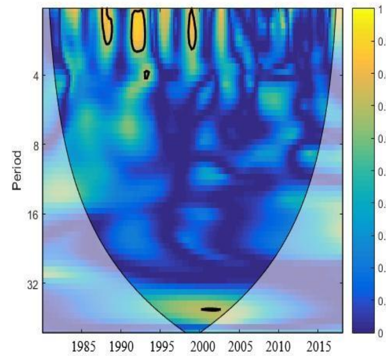

Figure 7b. PWC CO_2E - GDPPC - TECHI

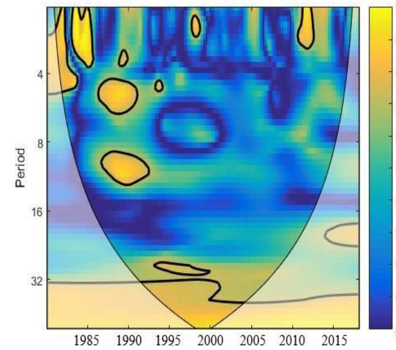

Figure 7c. PWC CO_2E - TECHI - GLOEI

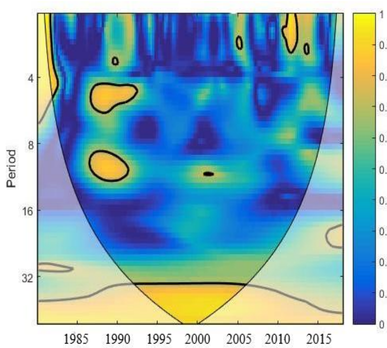

Figure 7d. PWC CO_2E - TECHI - GDPPC

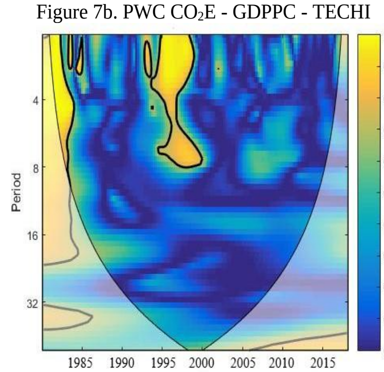

Figure 7e. PWC CO_2E - GLOEI - TECHI

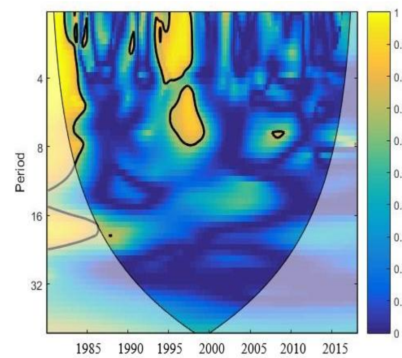

Figure 7f. PWC CO_2E - GLOEI - GDPPC

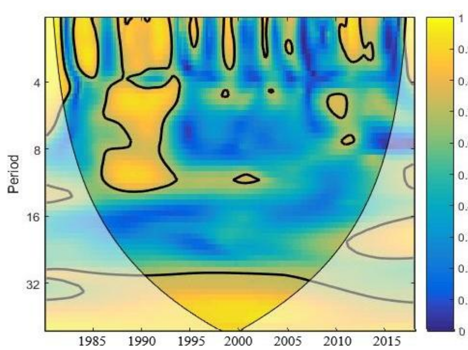

Figure 8a. MWC CO_2E - GDPPC - TECHI

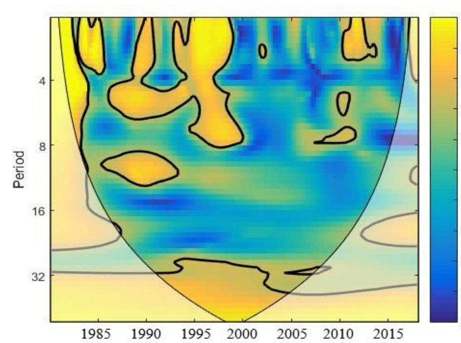

Figure 8b. MWC CO_2E TECHI GLOEI

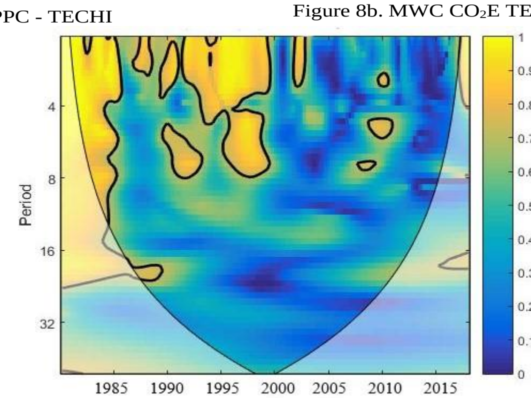

Figure 8c. MWC CO_2E - GDPPC - GLOEI