Environmental Kuznets Curve: A New Functional Form in the Case of Low-Income Countries

Yara Elsehaimy and Dina M. Yousri

Abstract

Since the late 1980s climate change as an incessant controversial topic has occupied the agenda of the top economies, sparking a heated debate among researchers, policy-makers, and international organizations. IMF argued that climate change imposes a huge threat on the long-run development and growth of world nations. While trying to capture the real drivers behind it, the United Nations (UN) reveals that CO_2 emissions that contribute to more than 66% of the greenhouse gases can be claimed responsible. Hence, uncovering the relationship between CO_2 emissions and countries' economic growth is vital. To assess the relationship between CO_2 emissions and economic growth, the paper will use the Environmental Kuznets' Hypothesis (EKC). The previous empirical findings on EKC hypothesis found a bidirectional relationship between CO_2 emissions and growth. Thus, a new functional form is introduced to capture the empirical literature as well as test the normal functional form. Using ARDLand stability testing as econometric techniques. Employing time-series data approaches for 60 years from 1960 to 2018 for the low-income countries group. The results are robust and support the presence of both EKC and its extended version in the long-run in some low-income countries.

Keywords

Environmental Kuznets curve • Co_2 emissions • Economic growth • ARDL • Co-integration • Low-income countries • Green House Gases (GHG)

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1 Introduction

> Global warming has reached a level such that we can ascribe with a high degree of confidence a cause-and-effect relationship between the greenhouse effect and observed warming…In my opinion, the greenhouse effect has been detected, and it is changing our climate now. Dr. James Hansen, testimony before U.S. Senate of Energy and Natural Resources Committee in Congress, 1988.

Since 1988, Climate change is a non-ending controversial topic on the agenda of top economies, policy-makers, international organizations, and researchers. The entire globe has been hit by atypical weather and the hottest temperatures on record. Given the accrues in the average global temperature a series of events are anticipated such as forest fires, droughts, huge storms, unusually cold winters, and floods. These forms of environmental degradations driven by human activities and burning of fossil fuels that increased the release of carbon dioxide (Greenhouse gases) in the atmosphere (WHO, 2018). According to IMF (2020), climate change is imposing a serious threat on the economic well-being and long-run growth of world nations. Green House Gases (GHG) is the main contributor in climate change issues grew by 1.5% from 2009 to 2018, hitting a new peak of 55.3 Giga Tone Carbon Dioxide Equivalent (GT CO_2E2) (Emission Gap Report, UN 2019). With CO_2 consisting of 66% of the total emission GHG and the rest 34% attributed to other gases, studying CO_2 emissions' effect on global economies become a must (Akbostanci et al., 2009; Emissions Gap Report, UN 2019).

Increasing levels of CO_2 emissions are driven by increasing levels of economic growth, population, and energy consumption, according to the Kaya identity equation (Kaya & Yokobori, 1997; Stern & Stern, 2007). On the other hand, lowering CO_2 emissions will decrease economic growth; because energy consumption and specifically CO_2 is the key part of production (Ahmad et al., 2017; Al-Mulali & Sab, 2012; Amano, 1993; Ang, 2007; Asafu-Adjaye, 2000; Fan et al., 2010; Hourcade & Robinson, 1996; Mahadevan

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& Asafu-Adjaye, 2007; Omri, 2013; Omri et al., 2014; Sadorsky, 2011). These controverting arguments have been reflected into three strands of theoretical and empirical literature in the climate change area.

The first strand is pioneered by Kraft and Kraft (1978), where the two economists studied the relationship between energy consumption and gross national income as an indicator for economic growth. Furthermore, the second strand is pioneered by the work of Grossman and Krueger (1991), which is built on Kuznets' Inverted U Inequality Hypothesis. Moreover, the third strand was analyzing the intersection of the first two strands, where researchers empirically examine the dynamic relationship between EG, EC, and environmental pollutants. Economic growth is not only an indicator for the Gross Domestic Product (hereafter GDP) or GNP, but also macroeconomic and financial indicators such as foreign direct investment, trade, financial development indexes.

According to Stern (2004), the negative consequences of climate change are greater than that of WWI and WWII. Thus, empirical studies on the effect of CO_2 emissions on economic growth are of a great importance. Hence, Environmental Kuznets Curve (EKC) is still relevant today and considered a cornerstone in analyzing the environmental degradation in the world. Most of the empirical findings goes in line with EKC hypothesis where a unidirectional causality running from economic growth to CO_2 emissions is present. Furthermore, recent studies have shown a bidirectional causality runs between CO_2 emissions and economic growth, in addition to the unidirectional causality (Acaravci & Ozturk, 2010; Acheampong, 2018; Ahmad et al., 2017; Al-mulali & Sab, 2012; Chang, 2010; Coondoo & Dinda, 2002; Dinda & Coondoo, 2006; Farhani et al., 2014; Ghosh, 2010; Govindaraju & Tang, 2013; Halicioglu, 2009; Lau et al., 2014; Omri et al., 2014; Pao et al., 2011; Pao & Tsai, 2011; Saboori & Sulaiman, 2013; Shahbaz et al., 2013; Tiwari et al., 2013; Zakarya et al., 2015). As a result, the empirical foundation of EKC hypothesis requires an extension to allow for testing economic growth as a function of CO_2 emissions (Extended Environmental Kuznets' Curve—EEKC), besides testing the original hypothesis, which is CO_2 emissions as a function of economic growth (EKC). Therefore, our research will examine the existance of the EEKC hypothesis as well as the EKC.

This study will focus on low-income countries (as per World Bank classification) given that they are known to be more vulnerable to climate change and suffering from several macroeconomic imbalances, institutional problems (corruption), over population, high illiteracy rates, lower productivity levels and generally low quality of life (Al-mulali & Sab, 2012). Moreover, an increase in economic growth seems an obvious target to this income group. Given the dynamic relationship between economic activities and climate change. A time-series data analysis will be employed to capture it from 1960 till 2016. For countries Burkina Faso, Ethiopia, Madagascar, Malawi, Mozambique, Guinea, Sierra Leon, Sudan, Chad, Malawi, Togo, Guinea, Guinea Bissau, Haiti, and Gambia. The uniqueness of this research is in the sample selected and the long time frame covered.

2 EKC Hypothesis: Previous Empirical Findings

Examining Environmental Kuznets Curve hypothesis is pioneered by the seminal paper of Grossman and Krueger (1991). The study was consisting of three main research questions; the first one studies the relationship between air quality and economic growth using panel data in 42 countries. While the second question examined the determinants of trade between the USA and Mexico and whether environmental pollution in the USA affects the trade with Mexico. The third question tackles the effect of pollution on the NAFTA trade agreement. In the first question, Grossman and Krueger (1991) using random estimation technique for 42 countries with daily records of three environmental pollutants for on average 2 years, found that sulfur dioxide and smoke are the main contributors to the changes that occur in growth in low-income countries; however, these two pollutants emissions were decreasing in high-income countries. In testing the following two questions, Grossman and Krueger (1991) used random estimation regressions and computable general equilibrium in the USA, Mexico, and Canada, the results showed that the environmental pollutants decrease after exceeding an income threshold for the sample courtiers, as well as, production in the USA is capital intensive, while labor-intensive in Mexico. In testing paper questions, Grossman and Krueger (1991) utilized Simon Kuznets' econometric technique in capturing income inequality, which is through adding squared and quadratic terms of GDP. This technique is then used extensively in the second strand of literature and named after Environmental Kuznets Curve (EKC) hypothesis.

EKC hypothesis testing continues to develop with the attempts of economists to validate its existence, which is, environmental deterioration measured through CO_2 emissions is increasing in the early stages of development; but lessens as the country develop and have higher economic growth. Moreover, the EKC hypothesis is identified through the presence of an inverted U-shaped relationship between CO_2 emissions and economic growth (Coondoo & Dinda, 2002). Empirically, GDP and GDP squared are incorporated with CO_2 emissions to test for the EKC hypothesis, if the GDP coefficient is positive and GDP square has a negative coefficient; therefore, the EKC hypothesis is confirmed (Acaravci & Ozturk, 2010; Coondoo & Dinda, 2002; Dinda, 2004). Coondoo and Dinda (2002) added that in the EKC hypotheses, CO_2 emission is a function of economic growth, which is consequently resulted in an expected unidirectional causality running from growth to emissions.

In testing 88 countries over 1960–1990, Coondoo and Dinda (2002) used ordinary least squares (OLS), ARDL bound test for co-integration, and Granger causality to investigate the causal relationship between income and CO_2 emissions. The findings demonstrated that for the developed country groups of North America, Western, and Eastern Europe, causality runs from CO_2 emission to income. Besides, for the country groups of Central and South America, Oceania and Japan causality runs from income to CO_2 emission is obtained. Lastly, for the country group of Asia and Africa, causality is found to be bidirectional between CO_2 emissions and income.

On the other hand, Friedl and Getzner (2003) used a time-series approach to check for the validity of EKC hypothesis in Austria from 1960 to 1999 by using OLS, co-integration technique based on Durbin Watson statistic and stationery as econometric techniques. The study findings emphasized that the relationship between CO_2 emissions and economic growth is N-shaped; thus, EKC hypothesis validity is rejected. Likewise, Akbostancı (2009) tested the validity of EKC in India from 1971 till 2006 using ARDL and Granger causality econometric technique. The results illustrated that EKC hypothesis does not hold in the long-run, as well as, there is no co-integration between the variables.

Furthermore, Galeotti and Lanza (2005) examined the EKC hypothesis for a panel consisting of 100 countries from 1980 till 2005. The findings showed that using different functional forms as linear and log-linear forms will lead to the same finding, which is the confirmation of EKC in the tested sample. Galeotti and Laanza (2005) used the OLS estimation technique in investigating EKC hypothesis for panel data. Besides, using panel data set for 29 provinces in China from 1995 till 2012, Hao et al. (2016) investigated the presence of EKC hypothesis through economic growth and coal consumption and incorporating population density along with urbanization rate. The study findings confirmed the validity of EKC hypothesis in China.

Additionally, Coondoo and Dinda (2006) studied the causal relationship between income and CO_2 emissions through a panel dataset for 88 countries from 1960 till 1990. The study incorporates OLS, ARDL bound test, Granger causality, and ECM for testing the research question. The findings of the study supported the presence of bidirectional causality runs between CO_2 emissions and income in the following subgroups, Africa, Central America, America as a whole, Eastern Europe, Western Europe, Europe as a whole, and the World as a whole. Important to realize that the movement of either CO_2 emissions or economic growth will directly affect the other, which is Coondoo and Dinda (2006) and Omri et al. (2014) named as feedback system; thus, decision-makers should pay huge attention to feedback system in order to achieve the highest economic return as possible. Omri et al. (2014) added that the relationship between CO_2 emissions and economic growth can be neutral, in which there is no relationship between them and it is called the neutrality hypothesis.

Comparatively, Ghosh (2010) scrutinized the relationship between CO_2 emissions and economic growth by incorporating energy supply, investment, and employment levels. The study examined the Indian economy from 1971 to 2006, using ARDL bound test and granger causality as econometric techniques. The study exhibited that there is no long-run co-integration or causality relationship between CO_2 emissions, and economic growth. However, there is a short-run bidirectional causality runs between CO_2 emissions and economic growth.

Nasir and Rehman (2011) analyzed the relationship between CO_2 emission, energy consumption, and economic growth by incorporating foreign trade with time-series data approach for Pakistan from 1972 till 2008. The results reveal that the EKC hypothesis is not confirmed in the economy. Nasir and Rehman (2011) emphasized that the study results are unique from the literature; as none of the variables are significant in the applied regression of the EKC hypothesis. Nevertheless, Al-Mulali et al. (2015) explore the EKC hypothesis in Vietnam from 1981 till 2011. The results manifested that the Vietnamese economy did not exhibit the EKC hypothesis; but rather a monotonic increasing relationship between the variables.

Indeed, time-series data is used more extensively in testing the EKC hypothesis; as it better capture the long-run dynamics considering the special economic and environmental nature of each country (Akbostancı et al., 2009). Using time-series approach, Jaunky (2011) examined 36 high-income countries from 1980 to 2005 through GMM econometric techniques. The study findings confirm the validity of EKC hypothesis in Greece, Malta, Oman, Portugal, and the United Kingdom. In addition, Jaunky (2011) examined 36 high-income countries with panel VECM Granger causality for the same period of time; however, the results did not support the existence of the EKC hypothesis.

Govindaraju and Tang (2013) investigated the EKC hypothesis using CO_2 emissions and real economic growth (GDP) incorporating coal consumption. Time-series approach was used for India and China over the period 1965–2009. Besides, Bayer and Hank co-integration test, where multiple co-integration tests are used to provide a conclusive co-integration finding and Granger causality are used as econometric techniques. The findings showed that there is a long-run co-integration relationship between CO_2 emissions, growth, and coal consumption, as well as, a unidirectional causality runs from growth to CO_2 emissions in China. For India, there is only a bidirectional causality run between CO_2 emissions and economic growth.

Moreover, Lau et al. (2014) explore EKC hypothesis using CO_2 emissions and real economic growth (GDP) incorporating foreign direct investment and trade openness. Time-series data approach was applied with ARDL bound test for co-integration and Granger causality for Malaysia from 1970 to 2008. The study findings confirmed the validity of EKC hypothesis in the country; however, the hypothesis is confirmed only with controlling foreign direct investment (FDI) and the trade size of Malaysia. Besides, bidirectional causality runs between CO_2 emissions and economic growth have also been found.

Nevertheless, Ahmad et al. (2017) examined the validity of EKC hypothesis in Croatia for 1992Q1 to 2011Q1 with ARDL, VECM, and Granger causality econometric techniques. The findings support the validity of EKC hypothesis in Croatia. As well as, there is bidirectional causality runs between CO_2 emissions and economic growth in the short-run. On the long-run, there is a unidirectional causality runs from economic growth to CO_2 emissions. The study applies DOLS and FMOLS as robustness techniques for the long-run relationship, and it indicated the same findings.

All the studies that investigate EKC hypothesis used CO_2 emissions as the functional form of economic growth that demonstrates a unidirectional causality runs from economic growth to CO_2 emissions and not vice versa (Coondoo & Dinda, 2002). However, many of the empirical studies found a bidirectional causality relationship runs between emissions and growth, as well as a unidirectional causality runs from CO_2 emissions to economic growth (Acaravci & Ozturk, 2010; Acheampong, 2018; Ahmad et al., 2017; Al-mulali & Sab, 2012; Chang, 2010; Coondoo & Dinda, 2002; Coondoo & Dinda, 2006; Farhani et al., 2014; Ghosh, 2010; Govindaraju & Tang, 2013; Halicioglu, 2009; Lau et al., 2014; Pao & Tsai, 2011; Pao et al., 2011; Saboori & Sulaiman, 2013; Shahbaz et al., 2013; Tiwari et al., 2013; Omri et al., 2014; Zakarya et al., 2015). Thus, the research will introduce an extension to EKC hypothesis (hereafter Extended Environmental Kuznets Curve—EEKC), in which economic growth will be tested as a function of CO_2 emissions, based on the previous empirical results found in literature. As well as, the research will be also test the validity of EKC hypothesis (hereafter NEKC).

3 Methodology

The objective of the paper is to validate EKC hypothesis and its extended version (EEKC) by examining the relationship between economic growth and CO_2 emissions. The research gathers data set from World Bank and OECD databases for the 15 countries in the low-income category from 1960 until 2018, which is the longest period used in assessing the paper objective.

In 1991, and after Grossman and Krueger's paper that introduces the EKC hypothesis, economists start to use a wide different range of techniques, methodologies and variables to examine the relationship between CO_2 emissions and economic growth. This array of differences between researches resulted in three distinct schools in analyzing CO_2 emissions and economic growth. As discussed earlier, each school has its group of variables in analyzing our relation of interest. According to Saboori et al. (2012), Riti et al. (2017), Ahmad et al. (2017), Akbostancı et al. (2009), the theoretical basis for the EKC hypothesis is as follows:

$$C_T = f\left(Y_T, Y_T^2, K_T\right) \tag{1}$$

where C_T represents Carbon Dioxide (CO_2) emissions, Y_T represents gross domestic production (GDP), Y_T^2 represents gross domestic production (GDP) squared, and K_T represents other variables that can cause changes in CO_2 emissions. Saboori et al. (2012), Riti et al. (2017), Ahmad et al. (2017), Du et al. (2012), Yavuz (2014) added that examining the effect of CO_2 emissions on GDP should be kept in the reduced functional form without including further explanatory variables. So that the investigated relationship kept direct, eliminating the risk of omitting relevant variables; due to data unavailability, and reducing the risk of analytical freedom and keeping the model parsimonious. Therefore, the investigated model of the Environmental Kuznets Curve will be as follows:

$$C_T = \alpha_0 + \beta_1 Y_T + \beta_2 Y_T^2 + \varepsilon_T \tag{2}$$

where C_T represents Carbon Dioxide (CO_2) emissions, α_0 is the equation constant intercept, that represents a statistical need and does not have an economic explanation. β_1 and β_2 are the two coefficients of the explanatory variables. Y_T represents gross domestic production (GDP), Y_T^2 represents gross domestic production (GDP) squared. The empirical-based extension for the EKC hypothesis that is suggested by the research has the following functional form:

$$Y_t = \alpha_3 + \beta_1 C_t + \beta_2 C_t^2 + \varepsilon_t \tag{3}$$

where Y_T represents gross domestic production (GDP), α_3 is the equation constant intercept that represents a statistical need and does not have an economic explanation. β_4 and β_5 are the two coefficients of the explanatory variables. C_t represents Carbon Dioxide (CO_2) emissions and C_t^2 represents Carbon Dioxide (CO_2) emissions squared.

According to (Acaravci & Ozturk, 2010; Ahmad et al., 2017; Akbostancı et al., 2009; Friedl & Getzner, 2003; Wang et al., 2011), β_1 is expected to have a positive sign, which represents the direct relationship between emissions and GDP, when the total production increases, CO_2 emissions should increase as well. While β_2 is expected to have a negative sign ($\beta_2 < 0$), which confirms the presence of EKC hypothesis. Which means the relationship between CO_2 emissions and GDP is captured by an inverted U-shaped curve, through which GDP growth threshold can be calculated, the income level at which CO_2 emissions will decline. If $\beta_1 < 0, \beta_2 = 0$ or $\beta_1 > 0, \beta_2 = 0$, there will be linear increasing or decreasing relationship based on the sign of β_1. If $\beta_1 < 0, \beta_2 > 0$, the relationship will be U-shaped. If $\beta_1 > 0, \boldsymbol{\beta}_2 < 0$, the relationship will be inverted U-shaped. Besides, the threshold point of GDP will be calculated as follows: $Y_T = -\frac{\beta_1}{2\beta_2}$ (Ahmed et al., 2017; Akbostancı et al., 2009; Apergis & Payne, 2009; Friedl & Getzner, 2003). Data used are extracted from World Development Indicators by World Bank Statistics annually from 1960 till 2016 using ARDL econometric modeling.

4 Results and Disscussion

According to Table 1, Burkina Faso ARDL test result shows that when GDP changes by 1 unit, CO_2 emissions increase by 29.75 units and 7.279 units in present year and the first one, respectively. Besides, when $GDPG^2$ changes by 1 unit, CO_2 emissions decreases by 2.8476 units, which confirms the presence of EKC hypothesis in Burkina Faso with 99% R^2. Nevertheless, in testing the suggested extension of EKC hypothesis at which GDPG is a function of CO_2 emissions, the results show that when CO_2 increases by 1 unit, GDPG will increase by 0.00462. Also, ${CO_2}^2s$ emissions have a negative coefficient of 1.15E−06, which proves that EEKC hypothesis is also held in Burkina Faso.

EKC hypothesis is confirmed in Ethiopia due to the negative and significant coefficients of GDPG squared with 2.111 value in year one with 10% significance. As for the relationship between CO_2 emissions and GDPG, the coefficient results of GDPG are as follows, 23.27963 at year zero with 5% significance, −29.697 at year one with 5% significance, 26.1633 at year two with 10% significance and −24.17158 at year three with 10% significance. Thus, the net effect between emissions and growth is −4.42613, indicating that when GDPG increases by 1 unit, CO_2 emissions will on average decrease by 4.42613 units. Identically, the EEKC is also confirmed with the negative and significant net coefficient at CO_2 emissions squared of 1.94E−07. Similarly, the relationship between CO_2 emissions and GDPG is changing over time, as in year zero, the relationship is positive at 0.018538 with 1% significance, while at year one, the relationship becomes negative with 1% coefficient with 0.0260, and in year two, the relationship turns to be positive once more at 5% significant with 0.011853 coefficient values. The net effect between CO_2 emissions and GDPG is 0.004391, when CO_2 emissions change by 1 unit, GDPG will increase by 0.004391.

Regarding Gambia, the, ARDL results do not confirm the presence of both normal and EEKC hypotheses in the country. As for the EKC, GDPG coefficients are as follows, when GDPG increases by 1 unit at year one, CO_2 emissions will increase by 2.47 units, as well as when GDPG increases by 1 unit at year two, CO_2 emissions will increase by 4.459596 units, both with 5% significant level. Besides, GDPG squared term is a positive value of 0.112735 at the fourth lag with 5% level of significance. As the result, the shape of the relationship between CO_2 emissions and GDPG is linear increasing line instead of an inverted U-shaped curve. For the extended version, when CO_2 emissions increase by 1 unit, GDPG will increase at year zero with 1% level of significance. GDPG squared has a negative coefficient of 0.000229 at year zero, however, it turns to be positive at year one with coefficient value of 0.000241, and both have 1% level of significance with a net effect of CO_2 square on growth at 0.000012 units.

Table 1 ARDL test results for three low-income countries

	Dependent	CO_2	${CO_2}^2$	GDPG	$GDPG^2$	R^2 (%)
Burkina Faso	CO_2	$(0.789)_{-1}$*** $(0.2916)_{-2}$*		(29.75)** $(7.279)_{-1}$**	(−2.8476)**	99
	GDPG	(0.00462)***	(−1.15E−06)***	$(-0.227)_{-1}$**		15.84
Burundi	CO_2	$(1.009)_{-1}$***		(0.559)	(−0.0529)	90.6
	GDPG	(−0.0362)*	(5.54E−05)	$(-0.01487)_{-1}$		7.998
Chad	CO_2	(1.007132)***		(0.099641)	(−0.017673)	96.257
	GDPG	(−0.058947)*** $(0.082487)_{-1}$***	(5.56E−05)*** $(-7.50E-05)_{-1}$***	(0.187887)***		17.778

Due to space issues; The rest of the results are available upon request

Furthermore, Guinea findings illustrate that when GDPG increases by 1 unit, CO_2 emissions decrease by 36.586 units in year zero at 10% significance, continue to decrease in year one with 174.46 coefficient at 1% significance, then start to increase in year three with 53 units at 5% significance, and 85.2829 units in year four at 1% significance. Due to the changing behavior of CO_2 emissions in relationship with GDPG, the study calculates the net effect coefficient between two variables at −68.7428, in which, in the long-run, when GDPG increases by 1 unit, CO_2 emissions will decrease by 68.7428 units. As well, the net coefficient of GDPG squared is 24.7, where GDPG squared changes by 1 unit, CO_2 emissions will increase by 24.7 units. However, in the extended hypothesis, when GDPG changes by 1 unit, CO_2 emissions increase by 3.44E−06 units. And when GDPG squared changes by 1 unit, CO_2 emissions decrease by 0.092132 units. Thus, the relationship between CO_2 emissions and GDPG in the EEKC will be an inverted U-shaped curve; as the coefficient of GDPG is positive while the coefficient of GDPG squared is of negative sign.

Guinea Bissau, EKC hypothesis coefficients show that the relationship between CO_2 emissions and GDPG is negative, in which, higher levels of GDPG will lead to lower levels of emissions. Identically, net coefficient of GDPG squared is also negative, in which, higher levels of GDPG squared will lead to lower levels of emissions. Therefore, the regression graph is downward sloping line with one intersection between CO_2 and GDPG. The research then will calculate the point of intersection between two variables; in order to identify where Guinea Bissau is from the dynamics between two variables under study. While EEKC is not hold in Guinea Bissau; due to the insignificance of CO_2 and CO_2 squared emissions.

Regarding Haiti NEKC hypothesis, the relationship between CO_2 emissions and GDPG is positive, when GDPG increases by 1 unit, CO_2 emissions increases by 19.88749 in year zero at 1% significance, but, in year three emissions decrease by 9.258 units at 10% significance. Consequently, the net coefficient of GDPG is 10.6291, in which on the long-run when GDPG increases by 1 unit, the emissions will increase on average by 10.6291 units. GDPG squared shows a negative relationship with CO_2 emissions is year zero with 2.04846 coefficient at 1% significance and a positive one in year one with 2.40639 coefficient at 5% significance. The net coefficient of GDPG squared is 0.35793, in which on the long-run when GDPG squared increases by 1 unit, the emissions will increase on average by 0.35793 units.

EEKC hypothesis of Haiti shows variation in coefficients of CO_2 emissions over year zero, one, three, and four at 1% level of significance, except for year three at 5% level of significance. Thus, the net effect of CO_2 emissions coefficient is −0.006128, when CO_2 emissions increases by 1 unit, GDPG will decrease by 0.006128. Also, the net coefficient effect of CO_2 emission squared is 0.00000652, when CO_2 emissions squared increases by 1 unit, GDPG will increase by 0.00000652. EEKC hypothesis will have U-curve shaped graph, representing the relationship between examined variables.

Madagascar findings illustrate that EKC hypothesis is confirmed with the significance of both GDPG and GDPG squared, besides the negative sign of the latter. When GDPG increases by 1 unit, CO_2 emissions increases by 19.87 units, indicating the direct and positive relationship between two variables. Moreover, GDPG squared has a negative coefficient of 2.606 at year zero that turns to be positive value of 2.4 in year one, and lastly turns to negative again with coefficient 2.96711 in year two; thus, the net effect of GDPG squared is −3.167394. Coefficients in Madagascar are all significant at 99% level of confidence. On the other hand, EEKC hypothesis findings demonstrate that it is not confirmed; due to the insignificance of CO_2 emissions square. Yet, CO_2 emissions show 5% significance findings with 0.008097 and −0.007122 at year one; as the result, when CO_2 emissions increases by 1 unit, GDPG will increase by 0.000975 units on average.

Malawi findings show that EKC hypothesis do not hold in the country; due to the insignificance of both GDPG and GDPG squared, yet, extended hypothesis is confirmed. For the extended hypothesis, when CO_2 emissions increase by 1 unit, GDPG will decrease by 0.041569 as a net effect over the long-run. But, the relationship between emissions and growth is positive at year zero with 0.070142 coefficient with 5% significance, however, it turns to be negative in the following year with 0.111711 coefficient values at 1% level of significance. As for GDPG squared, it has a net positive coefficient of 0.0000255 over the long-run. However, on the short-run, GDPG squared has a negative relationship with 0.0000306 coefficient value. Thus, on the short-run, Malawi EEKC hypothesis graph will have the shape of inverted—U-curve, while U-curve on the long-run.

Moving to Mali's economy, the findings confirm the presence of EKC hypothesis in the country. When GDPG increases by 1 unit, CO_2 emissions will increase by 5.9 units. Besides, GDPG squared has negative and 1% significant coefficient of 0.473492 value, indicating that Mali has the typical inverted U-shaped curve. Yet, the EEKC is not confirmed; due to the insignificance of both CO_2 emissions and CO_2 emission squared.

Identically, Mozambique findings confirm the presence of NEKC hypothesis with the 10% significance of both GDPG, and GDPG squared. Accordingly, when GDPG increases by 1 unit, CO_2 emissions increase by 56.60425 units, indicating that slight increase in production in the country, emissions will be more than doubled. Besides, when GDPG squared increases by 1 unit, emissions will decrease by 2.050 units, indicating the presence of normal inverted U- shaped curve for EKC. Albeit, the findings do not confirm the presence of the EEKC hypothesis in Mozambique; due to the insignificance of both CO_2 and CO_2 squared emissions.

Comparatively, Sierra Leone findings show non-existence of EKC hypothesis; due to the insignificance of GDPG squared term. However, findings verify a positive and 1% significant relationship between CO_2 emissions and GDPG. In which, GDPG increases by 1 unit, CO_2 emissions will increase by 5.6877 units. On the other hand, EEKC hypothesis is confirmed in Sierra Leon, where net effect of CO_2 squared coefficient is −0.0000126. In which, CO_2 emissions increases by 1 unit, GDPG wil1 increase by 0.0000376 at year zero and then decreases in the following year by 0.0000502, both at 10% level of significance.

Moreover, Sudan findings support the non-existing EKC hypothesis; due to the insignificance of GDPG coefficient. However, GDPG squared show negative and significant coefficient at 10%. The findings prove the presence of the diminishing feature of CO_2 with GDPG over years. Yet, the EKC hypothesis still does not hold in Sudan. On the other hand, the EEKC hypothesis is verified in Sudan. To emphasize, when CO_2 emissions increases by 1 unit, GDPG will increases at year one with 0.004284 coefficient at 10% significance, and with 0.004971in year three at 1% significance. As well, CO_2 squared has a negative coefficient of 2.36E−07 with 1% significance.

Togo findings support the non-existence of EKC hypothesis; due to the insignificance of GDPG. Yet, GDPG squared is negative and significant at 10%, indicating the presence of diminishing feature of CO_2 emissions; but the insignificance of GDPG leads to inconclusive results about the full shape of the curve. In addition to, the EEKC hypothesis does not hold on the long-run in Togo. Since, on the long-run, the net effect that CO_2 and CO_2 squared have is −6.3E−05 and 8E−07, respectively, on GDPG. Therefore, the relationship will be monotonic decreasing relationship. To emphasis, when CO_2 increases by 1 unit, GDPG will increase by 0.020169 units in year one with 1% significance, while will decrease by 0.020232 in year two with 1% level of significance. As well, CO_2 squared has a negative coefficient of 3.97E−06 at 1% significance in year one and positive coefficient of 4.77E−06 at year two with the same level of significance.

On the other hand, in testing EKC hypothesis presence in Chad the results does not confirm the presence of the hypothesis reflected in the insignificant coefficients. As well as, when testing the EEKC hypothesis, the results confirm the presence of the hypothesis. When CO_2 emissions change by 1 unit, GDPG decreases by 0.0726 in year zero, 0.0666 in year three and started to increase at year four with 0.0454. In which, the net effect of emissions on growth is a degreasing one with 0.0938 over years of analysis. The decreasing effect indicates that higher emissions that resulted in lower economic growth on the long-run. Nevertheless, emissions squared term is negative with 7.37E−05 coefficient, which confirms the presence of monotonic decreasing relationship, summerized in Table 1.

In addition to, Congo Demp. Rep. results show that neither EKC hypothesis nor the extended version is confirmed in the country. The two hypotheses cannot be confirmed due to the insignificance of GDPG squared and CO_2 squared terms, in normal and extended versions, respectively. However, in the NEKC hypothesis, the results show that when GDPG increases by 1 unit, emissions increase by 0.752941 units in year zero and 0.434001 in year three. Therefore, relationship between CO_2 emissions and GDPG is direct positive relationship with net effect of 1.18642 on the long-run. As well as, in the extended version, results show that when GDPG increases by 1 unit, emissions will decrease by 0.0022 units in second year lag.

Equally, Somalia findings illustrate the non-existence of both normal and EEKC hypothesis. However, only the GDPG is the insignificant variable in the equation, and GDPG squared has a net coefficient value of −0.2612 that confirms the presence of the diminishing feature CO_2 emissions in the long-run. But, the insignificance of GDPG leads to inconclusive insights about the trend of the relationship before the threshold point. Furthermore, the EEKC hypothesis is insignificant; due to the insignificance of both CO_2 and CO_2 squared emissions.

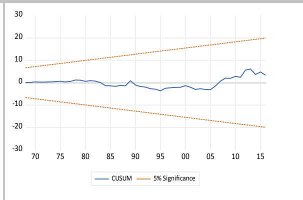
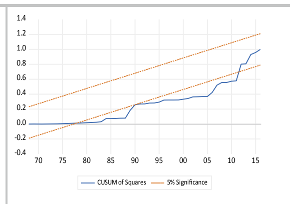
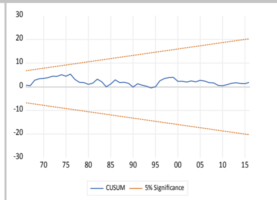
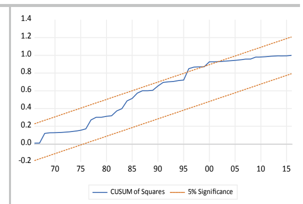
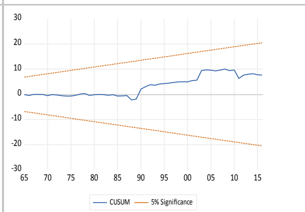
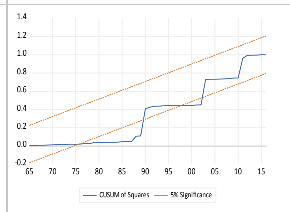
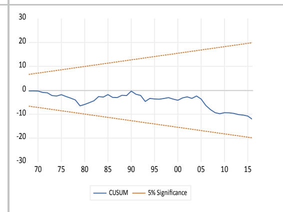
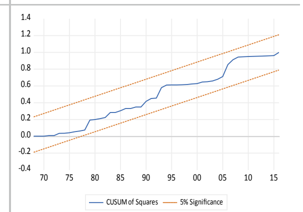
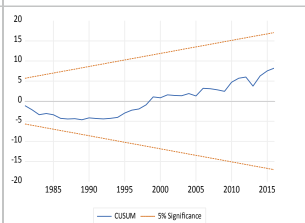
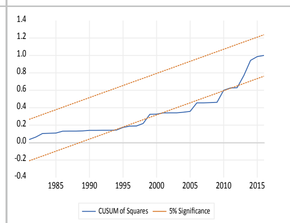
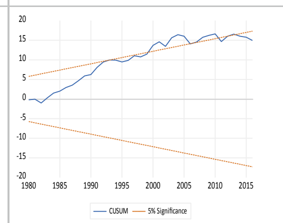
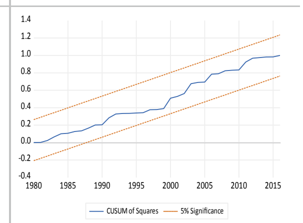
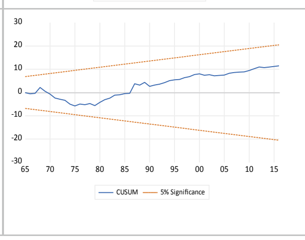
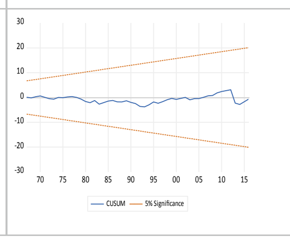
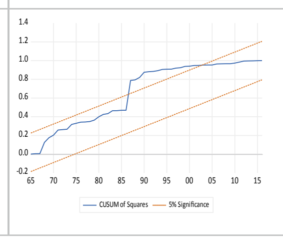
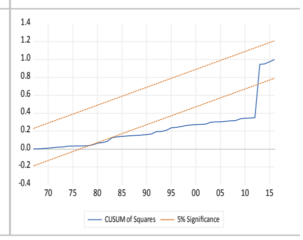
Lastly, in Burundi, Central African Republic (CAR), Niger, Rwanda, and Uganda both normal and EEKC hypothesis are not verified; due to the insignificance of GDPG in NEKC regression, as well CO_2 squared in the EEKC regression.

4.1 Stability Test

According to stability test results in Table 2, there are four main categories of stability test results of low-income countries. The first category is the countries where both normal and EEKC hypotheses are stable over time. In which, reliable policy recommendations and decisions can be made based on the estimated coefficients of both normal and EEKC; as they are stable over time. Countries that have stable normal and EEKC hypotheses are Chad, Ethiopia, Guinea, Guinea Bissau, Madagascar and Malawi.

Second, the following category contains countries where both normal and EEKC hypotheses are unstable over time. In which, accurate and effective decisions and recommendations cannot be made based on the estimated coefficients

Table 2 Stability test results for four low-income countries

Country	$CO_2 = f(GDP_g)$		$GDP_g = f(CO_2)$	
Burkina Faso				
Chad				
Gambia, the				
Central African Republic (CAR)				

Due to space issues; the rest of the results are available upon request

of both normal and EEKC; as the estimated relationship are not stable over time. Countries that have instable normal and EEKC hypotheses are Gambia, the, Mali, Niger, Togo, Uganda, represented in Table 2.

Third, this category contains countries where only NEKC hypotheses is stable over time and extended version is unstable (Table 2). In which, only the estimates of NEKC hypothesis can be used in decision making and policy recommendations and not extended version; as the normal one is only of stable estimates over long-run. Countries that have stable NEKC hypothesis and instable EEKC are Central African Republic (CAR), Rwanda and Sierra Leone.

Lastly, according to Table 2, the fourth category contains countries that have stable EEKC hypotheses. In which, only the estimates of EEKC hypothesis can be used in decision making and policy recommendations and not normal version; because the extended one is only of stable estimates over long-run. Countries that have stable EEKC hypothesis and unstable NEKC are Burkina Faso, Burundi, Congo Damp. Rep, Haiti, Mozambique, Somalia and Sudan.

5 Conclusion and Implications

Since CO_2 emissions are of the largest percentage from both energy consumption and greenhouse gases emissions; therefore, the study investigated the existence of the EKC hypothesis in low-income countries by examining the relationship between CO_2 emissions and economic growth proxy through GDP growth rates. According to EKC hypothesis, a unidirectional causality should run from GDPG to CO_2 emissions, supporting the used functional form used, which is CO_2 emissions is a functional form of GDPG. However, the exiting empirical finding in environmental literature is supporting the presence of bidirectional causality between CO_2 emissions and GDPG rates (see Table 1). Thus, the research will extend the EKC hypothesis with an additional functional form, in which GDP is a function of CO_2 emissions. The examined extension will be called extended environmental Kuznets curve (EEKC) and the normal environmental Kuznets curve will be called

(EKC). Both EKC and EEKC will be examined in the research through ARDL and stability econometric techniques. In addition to, the sample size will be from 1960 till 2016, which is the longest examined sample in EKC strand for Burkina Faso, Ethiopia, Madagascar, Malawi, Mozambique, Guinea, Sierra Leon, Sudan, Chad, Malawi, Togo, Guinea, Guinea Bissau, Haiti and Gambia.

The first group of countries consists of Burkina Faso and Ethiopia, where both EKC and EEKC hypotheses are confirmed. These countries have a positive long-run co-integration relationship between CO_2 and GDPG, where the production in the country increases, emissions also increase. According to EKC hypothesis, when GDPG reaches maximum of 2.04% and 5.513% for Burkina Faso and Ethiopia, respectively, emissions will start to decrease and growth will continue increasing. In addition to, EEKC hypothesis, GDPG will start to increase after the threshold of CO_2 emissions, which is 2008.696 and 9087.25 for Burkina Faso and Ethiopia, respectively. However, these countries should start to improve environmental laws and regulations in the economy, in which environmental constraints should be imposed on CO_2 emissions. Alternatively, the economy of these countries should be diversified and include service sector as well as industrial one.

The second group of countries consists of Madagascar, Malawi and Mozambique, where only EKC hypothesis is confirmed. Only Madagascar has positive long-run co-integration between emissions and economic growth. According to NEKC hypothesis, when GDPG reaches the maximum of 3.812%, emissions will start to decrease and growth will continue increasing. But, close attention to emissions level in the country, along with enhancing environmental regulations should be given. On the other hand, Mali and Mozambique have a positive relationship between emissions and growth. According to Akinlo (2008), in such case each country should revise its energy conservation policies appropriately, with regard to its conditions.

The third group of countries consists of Guinea, Sierra Leon, Sudan, Chad, Malawi and Togo, where EEKC hypothesis is confirmed. It is only confirmed in the short-run for Malawi and Togo. According to EEKC hypothesis, both GDPG and emissions will increase till reaching the maximum point of emissions, then emissions will decrease and growth will continue increasing. Nevertheless, these countries should start to improve environmental laws and regulations in the economy, in which environmental constraints should be imposed on CO_2 emissions. Alternatively, the economy of these countries should be diversified and include the service sector as well as the industrial one.

The last category consists of Guinea, Guinea Bissau, Haiti and Gambia, The, in which both EKC and EEKC are rejected and the data show another type of relationship. To start with, Guinea EKC and Haiti EEKC show a negative relationship between CO_2 and economic growth, where higher emissions resulting in lower growth. Therefore, higher production levels should be attained in both countries with enhancing the environmental quality regulations. While Guinea Bissau NEKC reveal a negative relationship between CO_2 emissions and GDPG, resulting in a monotonic decreasing relationship. Thus, the higher the growth will result in higher emissions and vice versa; so conservative energy consumption policies should be applied. In addition to, Haiti NEKC, and Gambia, the NEKC and EEKC shows a monotonic increasing relationship; thus, countries should apply restrict energy consumption regulations in favor for environmental quality. Besides, according to Pao and Tsai (2011), in order to reduce the negative effect of emissions on growth, governments should apply dual strategy, in which, investments in energy infrastructure increases, as well as, increase conservation policies. Consequently, the energy productivity will increase and energy wastes will sharply decrease.

References

Acaravci, A., & Ozturk, I. (2010). On the relationship between energy consumption, CO_2 emissions and economic growth in Europe. *Energy, 35*(12), 5412–5420.

Acheampong, A. O. (2018). Economic growth, CO_2 emissions and energy consumption: What causes what and where? *Energy Economics, 74*, 677–692.

Ahmad, N., Du, L., Lu, J., Wang, J., Li, H. Z., & Hashmi, M. Z. (2017). Modelling the CO_2 emissions and economic growth in Croatia: Is there any environmental Kuznets curve? *Energy, 123*, 164–172.

Akbostancı, E., Türüt-Aşık, S., & Tunç, G. İ. (2009). The relationship between income and environment in Turkey: Is there an environmental Kuznets curve? *Energy Policy, 37*(3), 861–867.

Akinlo, A. E. (2008). Energy consumption and economic growth: Evidence from 11 Sub-Sahara African countries. *Energy Economics, 30*(5), 2391–2400.

Al-Mulali, U., & Sab, C. N. B. C. (2012). The impact of energy consumption and CO_2 emission on the economic growth and financial development in the Sub Saharan African countries. *Energy, 39*(1), 180–186.

Al-Mulali, U., Saboori, B., & Ozturk, I. (2015). Investigating the environmental Kuznets curve hypothesis in Vietnam. *Energy Policy, 76*, 123–131.

Amano, A. (1993). Macroeconomic costs and other side-effects of reducing CO_2 emissions.

Ang, J. B. (2007). CO_2 emissions, energy consumption, and output in France. *Energy Policy, 35*(10), 4772–4778.

Asafu-Adjaye, J. (2000). The relationship between energy consumption, energy prices and economic growth: Time series evidence from Asian developing countries. *Energy Economics, 22*(6), 615–625.

Apergis, N., & Payne, J. E. (2009). CO2 emissions, energy usage, and output in Central America. *Energy Policy, 37*(8), 3282-3286.

Chang, C. C. (2010). A multivariate causality test of carbon dioxide emissions, energy consumption and economic growth in China. *Applied Energy, 87*(11), 3533–3537.

Christiansen, L., von Kursk, O. B., & Haselip, J. A. (2018). UN environment emissions gap report 2018.

Coondoo, D., & Dinda, S. (2002). Causality between income and emission: A country group-specific econometric analysis. *Ecological Economics, 40*(3), 351–367.

Dinda, S. (2004). Environmental Kuznets curve hypothesis: A survey. *Ecological Economics, 49*(4), 431–455.

Dinda, S., & Coondoo, D. (2006). Income and emission: A panel data-based cointegration analysis. *Ecological Economics, 57*(2), 167–181.

Du, L., Wei, C., & Cai, S. (2012). Economic development and carbon dioxide emissions in China: Provincial panel data analysis. *China Economic Review, 23*(2), 371–384.

Fan, Y., Zhang, X., & Zhu, L. (2010). Estimating the macroeconomic costs of CO_2 emission reduction in China based on multi-objective programming. *Advances in Climate Change Research, 1*(1), 27–33.

Farhani, S., Chaibi, A., & Rault, C. (2014). CO_2 emissions, output, energy consumption, and trade in Tunisia. *Economic Modelling, 38*, 426–434.

Friedl, B., & Getzner, M. (2003). Determinants of CO_2 emissions in a small open economy. *Ecological Economics, 45*(1), 133–148.

Galeotti, M., & Lanza, A. (2005). Desperately seeking environmental Kuznets. *Environmental Modelling & Software, 20*(11), 1379–1388.

Ghosh, S. (2010). Examining carbon emissions economic growth nexus for India: A multivariate cointegration approach. *Energy Policy, 38* (6), 3008–3014.

Govindaraju, V. C., & Tang, C. F. (2013). The dynamic links between CO_2 emissions, economic growth and coal consumption in China and India. *Applied Energy, 104*, 310–318.

Grossman, G. M., & Krueger, A. B. (1991). *Environmental impacts of a North American free trade agreement* (No. w3914). National Bureau of economic research.

Halicioglu, F. (2009). An econometric study of CO_2 emissions, energy consumption, income and foreign trade in Turkey. *Energy Policy, 37*(3), 1156–1164.

Hao, Y., Liu, Y., Weng, J. H., & Gao, Y. (2016). Does the environmental Kuznets curve for coal consumption in China exist? New evidence from spatial econometric analysis. *Energy, 114*, 1214–1223.

Hourcade, J. C., & Robinson, J. (1996). Mitigating factors: Assessing the costs of reducing GHG emissions. *Energy Policy, 24*(10–11), 863–873.

IMF. (2022). The IMF and climate change. IMF: https://www.imf.org/en/Topics/climate-change

Jaunky, V. C. (2011). The CO_2 emissions-income nexus: Evidence from rich countries. *Energy Policy, 39*(3), 1228–1240.

Kaya, Y., & Yokobori, K. (Eds.). (1997). *Environment, energy, and economy: Strategies for sustainability*. United Nations University Press.

Kraft, J., & Kraft, A. (1978). On the relationship between energy and GNP. *The Journal of Energy and Development*, 401–403.

Lau, L. S., Choong, C. K., & Eng, Y. K. (2014). Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: Do foreign direct investment and trade matter? *Energy Policy, 68*, 490–497.

Mahadevan, R., & Asafu-Adjaye, J. (2007). Energy consumption, economic growth and prices: A reassessment using panel VECM for developed and developing countries. *Energy Policy, 35*(4), 2481–2490.

Nasir, M., & Rehman, F. U. (2011). Environmental Kuznets curve for carbon emissions in Pakistan: An empirical investigation. *Energy Policy, 39*(3), 1857–1864.

Omri, A. (2013). CO_2 emissions, energy consumption and economic growth nexus in MENA countries: Evidence from simultaneous equations models. *Energy Economics, 40*, 657–664.

Omri, A., Nguyen, D. K., & Rault, C. (2014). Causal interactions between CO_2 emissions, FDI, and economic growth: Evidence from dynamic simultaneous-equation models. *Economic Modelling, 42*, 382–389.

Pao, H. T., & Tsai, C. M. (2011). Modeling and forecasting the CO_2 emissions, energy consumption, and economic growth in Brazil. *Energy, 36*(5), 2450–2458.

Pao, H. T., Yu, H. C., & Yang, Y. H. (2011). Modeling the CO_2 emissions, energy use, and economic growth in Russia. *Energy, 36* (8), 5094–5100.

Riti, J. S., Song, D., Shu, Y., & Kamah, M. (2017). Decoupling CO_2 emission and economic growth in China: Is there consistency in estimation results in analyzing environmental Kuznets curve? *Journal of Cleaner Production, 166*, 1448–1461.

Saboori, B., Sulaiman, J., & Mohd, S. (2012). Economic growth and CO2 emissions in Malaysia: A cointegration analysis of the environmental Kuznets curve. *Energy policy, 51*, 184–191.

Saboori, B., & Sulaiman, J. (2013). Environmental degradation, economic growth and energy consumption: Evidence of the environmental Kuznets curve in Malaysia. *Energy Policy, 60*, 892–905.

Sadorsky, P. (2011). Trade and energy consumption in the Middle East. *Energy Economics, 33*(5), 739–749.

Shahbaz, M., Hye, Q. M. A., Tiwari, A. K., & Leitão, N. C. (2013). Economic growth, energy consumption, financial development, international trade and CO_2 emissions in Indonesia. *Renewable and Sustainable Energy Reviews, 25*, 109–121.

Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve. *World Development, 32*(8), 1419–1439.

Stern, N., & Stern, N. H. (2007). *The economics of climate change: the Stern review*. Cambridge University Press.

Tiwari, A. K., Shahbaz, M., & Hye, Q. M. A. (2013). The environmental Kuznets curve and the role of coal consumption in India: Cointegration and causality analysis in an open economy. *Renewable and Sustainable Energy Reviews, 18*, 519–527.

Wang, S. S., Zhou, D. Q., Zhou, P., & Wang, Q. W. (2011). CO_2 emissions, energy consumption and economic growth in China: A panel data analysis. *Energy Policy, 39*(9), 4870–4875.

WHO. (2018). Climate change and health. https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health

Yavuz, N. Ç. (2014). CO_2 emission, energy consumption, and economic growth for Turkey: Evidence from a cointegration test with a structural break. *Energy Sources, Part B: Economics, Planning, and Policy, 9*(3), 229–235.

Zakarya, G. Y., Mostefa, B. E. L. M. O. K. A. D. D. E. M., Abbes, S. M., & Seghir, G. M. (2015). Factors affecting CO_2 emissions in the BRICS countries: A panel data analysis. *Procedia Economics and Finance, 26*, 114–125.