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Risk to investment and renewables production in the United States: An inference for environmental sustainability

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ABSTRACT

With the increasing drive toward cleaner environment, accessing lower risk investment with financing opportunities has remained a pertinent hurdle to achieving a paradigm shift from the business-as-usual approaches to a responsible climate actions and environmental awareness. On this note, the current study examined for the first time the impact of the risk to investment on environmental quality over the period of 1984–2017 for the case of the United States. Considering that the burning of fuels constitutes the largest source of Greenhouse gas in the United States, this study employed energy carbon emissions both as a proxy for environmental quality and dependent variable. The real Gross Domestic Product and renewable energy production were both incorporated in the carbon function model as an additional explanatory variable that was examined by a handful of empirical tools. Importantly, the study found that an associated lower risk to investment is a suitable and significant approach toward improving the quality of the environment in both the short and long run. Similarly, the production and utilization of renewable energy exhibits a statistically significant and desirable impact on environmental quality i.e renewable energy production and utilization improves environmental quality. However, the study found that economic expansion significantly spur hindrance to environmental sustainability. This study justifies that risk associated with all investment aspects is fundamental to environmental quality, and thus posing an indirect health and socioeconomic concerns. Additionally, the result proved that the circumstance of renewable energy waste and energy loss to transmission arising production-consumption disparity is negligible. Moreover, the robustness and diagnostic test affirms the validity of the investigation. Thus, this study proffers a relevant policy mechanism toward the attainment of the country's sustainable development goals via cleaner productivity, especially from the perspective of associated risks in public and private low-carbon and clean technologies financing.

1. Introduction

The dynamics in the business environment especially leading to the rapid transformation of the global economic activities and the business-as-usual has remained one of the 21st century's effective policy implementation toward achieving environmental sustainability. The global paradigm shift from the business-as-usual to the adoption of a more sustainable economic and business activity approaches is in response to the dire need to protect the human natures. This is why the global increase in environmental damages has continued to compel environmentalists, policymakers especially the intergovernmental agencies to further formulate frameworks that are designed for climate mitigation.

Abbreviations: ADF, Augmented Dickey-Fuller; ARDL, Autoregressive Distributed Lag; BTU, British Thermal Units; CCS, Carbon Capture and Storage; CO_2, carbon dioxide; CUSUM, Cumulative Sum; CUSUMsq, Cumulative Sum of Squares; ECT, Error Correction Term; ECEM, Energy Carbon Emissions; EIA, Energy Information Administration; FDI, Foreign Direct Investment; FRED, Federal Reserve Bank of ST Louis; GHG, Greenhouse gas; HDI, Human Development Index; INVEST, Investment Risk; IEA, International Energy Agency; IPCC, Intergovernmental Panel on Climate Change; KPSS, Kwiatkowski–Phillips–Schmidt–Shin; LM, Lagrange Multiplier; LN, Logarithm; M&A, Merger and Acquisition; PRS, Political Risk Service; RENEC, Renewable Energy Consumption; RENEP, Renewable Energy Production; RGDP, Real Gross Domestic Product; RP, Risk Premium; SDGs, Sustainable Development Goals; SR, Serial correlation; STIRPAT, Stochastic Impacts by Regression on Population, Affluence and Technology; UECM, Unrestricted Error Correction Model; UNCTD, United Nations Conference on Trade and Development; USD, United States Dollars; WDI, World Bank Development Indicator.

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In its reports, up to the ongoing sixth assessment report, the Intergovernmental Panel on Climate Change (IPCC) has consistently linked the global warming to the increase in human population, economic activity and lifestyle, use of energy and land, and others (Intergovernmental Panel on Climate Chang, 2019). This is a further affirmation to report of the National Aeronautics and Space Administration that there is about 95 percent certainty that human activities especially from non-renewable energy sources such as coal and oil are largely responsible for the global warming (National Aeronautics and Space Administration, 2020). Considering the endangering effect of global warming especially from the impact of investment and business dynamics, the associated and potential impact of risk to investment such as from the energy investment, manufacturing and other industry-related sources cannot be underestimated.

Because there is always an associated level of risk in public, private, and/or public-private partnership form of business or investment, thus compelling a trade-off between risk and reward is mostly inevitable. Perhaps, capital-intensive investments, and especially those with high return are associated with high risk (Corporate Finance Institute, 2020; United States Securities and Exchange Commission, 2020). Thus, from the perspective of investment-related risk, there are now increasing studies on environmental sustainability that entails climate actions such that is geared toward mitigating investment risks via low-carbon technologies (Islam et al., 2020; Senapati, 2020; Vajjarapu et al., 2020). According to the International Country Risk Guide (ICRG), the risks associated with (public, private, or public-private partnership) investment profile are largely driven from the subcomponents of contract viability or expropriation, profits repatriation, and payment delays (International Country Risk Guide, 2020). Generally, investment with a higher potential of return is mostly associated with higher risk which according to the Chartered Financial Analyst (CFA) Institute (2020) is inherent in the driving force of 'risk need', risk-taking ability', and behavioral loss tolerance'. The need to provide good and services, through infrastructural development arising from industrialization have significantly involved the participation of both the public and private partnership especially in the 21st century. Thus, public investments in infrastructure (such as telecommunication, transportation, and energy technologies) and current investment (such as welfare benefits) (Britannica, 2020), are now largely spiralling to capital investment such as company's acquisition through the real estate, industrial and manufacturing plant, (energy and environmental) technologies, production machineries, and others. In developed economies such as the United State, for instance, infrastructural development such as in transportation and development of alternative energy sources has continued to experience public and private support especially that are capable of minimizing environmental challenges (Umar et al., 2020). However, in looking at such economy's investment profile, it is an expected priority to examine the role of associated risk to investment on the drive toward environmental sustainability.

In term of the contribution of this study from the aforementioned motivations, especially regarding the associated risk of the United States' public and private investment profile, the current study is designed to examine how the implied risk (related with financing and other aspects) is linked with the country's environmental sustainability. In particular, this can be viewed from the perspectives of project-specific risk, industry-specific risk, competitive risk, international risk, and market risk (Corporate Finance Institute, 2020). Moreover, rather than utilizing the common area of FDI ((Ahmed et al., 2017), the associated risk of the aspects of both private and public sectors investment (total) is considered in the current study. In so doing, impact of risk associated with investment, the renewable energy production, and economic development vis-à-vis the real Gross Domestic Product (RGDP) on energy carbon emissions is examined over the period of 1984–2017. Importantly, the investment profile index of the Political Risk Services (PRS) provides the proxy for the associated risk on investment (https://www.prsgroup.com/explore-ourproducts/international-country-risk-guide/). Hence, by driving through achieving the study's objective, this study presents a novel approach that exhibit the potential of contributing to the body of knowledge on notable points. Foremost, from the authors' information, the current study is the first in the literature to examine the link between the associated risk to investment and environmental quality. In doing so, the current study potentially closes the gap in the study of Golub et al. (2019). In addition, by employing energy carbon emissions (exclusive carbon emissions from energy utilization) against the conventional carbon dioxide (CO_2) emissions from other sources, this study presents a novel approach with an underlying motive of understanding the contribution of overall (public and private) investment profile to the energy sector emissions. Furthermore, this study primarily and uniquely employed renewable energy production because of the close association between investment and production rather than investment and consumption. Lastly, the study has employed the Autoregressive Distributed Lag (ARDL) to reveal the short-run and long-run observations between the variables in addition to the use of both robustness and diagnostic methods to ascertain the relevance and validity of the study.

Accordingly, the other and succeeding sections are outlined as follows. In section 2, both the theoretical and empirical underpinning of the study as deduced from another related conceptual framework are presented. In section three, the material in addition to the employed empirical methods are carefully outlined. The discussion of the empirical results in addition to the diagnostic test observation are presented in section four. A concluding remark with policy recommendations form the components of section five.

2. Theoretical literature

Before now, preliminary studies have provided a guide to illustrate the drivers of environmental anthropogenic and have since been one of the underlying frameworks in environmental economics (Dietz and Rosa, 1994; York et al., 2003; Rosa et al., 2004). Following the aforementioned preliminary studies, several factor such as fertility, immigration, political institution policy, healthcare, energy sources, corruption, human development index, total resource rent, globalization, tourism, partisan conflict, and others have been incorporated into the STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) environmental concepts to examine the determinants of environmental sustainability (Shahbaz et al., 2018; Alola et al., 2019). Specifically, several studies such as Shahbaz et al. (2019) and Joshua and Alola (2020) have examined the link between investment especially in the concept of FDI and environmental quality.

2.1. Empirical literature

Unlike the aforementioned determinants of environmental sustainability, the risk to investment has not been investigated in the context of environmental quality. However, the risks associated with investment are categorized as inflation risk, return risk, capital risk, and currency risk (Competition and Consumer Protection Commission, 2020). Indicatively, the capital risk (such as examined by Golub et al., 2019) and return risk (as examined by Schmidt, 2014) are the respective risk categories associated with the investment capital and the return in the form of profit or dividends are also not without a level of associated risk. Whereas, the investments in a foreign currency such as the FDI are expectedly exposed to currency risk, the future prospect of the investment could dwindle due to inflation risk arising from the loss of value or buying power of the investment over a certain period. For instance, a hyperinflation period could pose a devastating loss to investments especially when there is no appropriate intervention or fiscal policy that is directed to cushion the effect of the inflation. Moreover, the perspective of the investors is also an important component of risks associated with investments (Sachse et al., 2012).

Furthermore, Schmidt (2014) considered the risks associated with investments especially in the developing economies as a source of concern to the actualization of environmental sustainability. Thus, the study opined that climate policy that is attractively conditioned for private low-carbon investments is essential in addressing the huge global investment challenge especially from the perspective of associated risk. Importantly, Schmidt (2014) offered two directions to the global investment challenge: 'first, increase the returns of low-carbon investments (or decrease those of high-carbon investments), and second, decrease the downside risk of low-carbon investments, also called de-risking'. Similarly, Blyth et al. (2007) employed the International Energy Agency (IEA)'s model that illustrates investment decisions in power generation from the perspective of a private company. The approached considered that most investments are conditioned on external risk factor such as climate policy that is characterized with high futuristic uncertainty that is beyond the respective company or establishment. Importantly, Blyth et al. (2007) found that a risk premium (RP) is created by climate policy uncertainty for power generation investments such that the RP is capable of causing a 5–10% hike in prices of electricity in order to trigger investment. In addition, the study found that the RP triggers the carbon price by 16–37% as to stimulate investment in carbon Capture and Storage (CCS) when compared with a risk-free situation.

Moreover, several other factors that affect carbon emission or environmental quality have been revealed in the literature. In addition to climate investment policy such as the low carbon roadmap of residential building sector (Ma et al., 2020), economic development among other factors are critical to the carbon mitigation policy and prospects. For instance (Ma et al., 2019), examined the link between the economic development in the Chinese's industrial sector and the possibility of decoupling from the carbon intensity in the commercial building sectors. By applying the decomposition and decoupling methods for the top five Chinese urban agglomerations, Ma et al. (2019) found that the carbon intensity decoupling status in the commercial sectors nationwide is weak and strong during the periods of 2001–2005 and 2006 to 2015 respectively. In term of the urban agglomeration, the study found that only four states satisfied the decoupling status. Largely, the carbon intensity decoupling status experienced in the commercial sector is linked to the significant of Carbon Kuznets curve hypothesis. A similar perspective of carbon decoupling from the perspective of human development index (HDI) was illustrated by Chen et al. (2020).

Although the body of knowledge is saturated with several dimensions to carbon mitigation and approaches to a net-zero carbon emissions, only spare studies have illustrated the investment risks aspect of the dialogue. Thus, the current study, as one of the rare studies, is not only looking at that direction, but empirically examining the role of investment risks amidst other factors on caron emissions.

3. Material and methods

This empirical study utilized the time series data that is balanced for the United States over the experimental period of 1984–2017. The dependent variable employed is the energy carbon emissions (ECEM) in a carbon function. Accordingly, the real gross domestic product (RGDP) (sourced from FRED, 2019), renewable energy production (RENEP), renewable energy consumption (RENEC), and the risk to investment vis-à-vis the investment profile (INVEST). Because of data limitation especially for the INVEST series, earlier experimental period (i.e before 1984) was not employed. However, other relevant information about the employed data is outlined in Table 1.

In addition to the aforementioned variable description of Table 1, the descriptive statistics of the investigated series is presented in the upper part of Table 2. From the observation, we found that the entire series employed are normally distributed except for the renewable energy production and renewable energy consumption. Similarly, except for the renewable energy production and consumption, the distribution of the series are all negatively skewed, thus illustrating that observations of the series are mostly positive. Additionally, the difference in the million metric tons of CO_2 from energy sources and the difference (in trillion Btu) of the production and consumption components of renewable energy are all inferred from the information in Table 2.

Table 1
Variable, Unit of measurement Variable.

Name	Code	Unit of measurement	Source
Energy carbon emissions[a]	ECEM	Million Metric Tons of CO_2	EIA
Renewable energy[b] production	RENEP	Trillion BTU	EIA
Renewable energy consumption	RENEC	Trillion BTU	EIA
Real gross domestic product	RGDP	USD annual rate of 2012	FRED
Investment profile	INVEST	Score of 12 = low risk, 0 = high risk	PRS

Note: BTU is the British Thermal Units (Btu), FRED is the Federal Reserve Bank of ST. Louis (FRED), EIA is the US Energy Information Administration, and PRS is the Political Risk Service while CO_2 is carbon dioxide. The renewable energy sources include hydroelectric power, geothermal, solar, wind, wood biomass, biofuels, and waste biomass.

[a] The EIA (US EIA, 2019) reported that about 46% of U.S. energy-related CO2 emissions in 2019 came from burning petroleum fuels, 33% came from burning natural gas, and 21% came from burning coal. Although the industrial sector is the largest consumer of energy (including direct fuel use and electricity purchases from the electric power sector), the transportation sector emits more CO2 because of its near complete dependence on petroleum fuels. The residential and commercial sectors have lower CO2 emissions levels than the transportation sector and the industrial sector. Most of the CO2 emissions associated with energy use by the residential and commercial sectors can be attributed to fossil fuel combustion by the electric power sector to produce the electricity that it sells to end users in those sectors.

[b] Additionally, the EIA noted that renewable energy is energy from sources that are naturally replenishing but flow-limited; renewable resources are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. The major types of renewable energy sources are Biomass (Wood and wood waste, Municipal solid waste, Landfill gas and biogas, Ethanol, and Biodiesel), Hydropower, Geothermal, Wind and Solar.

3.1. Model presentation

In investigating the factors responsible for environmental hazards or quality (using the carbon emissions or ecological footprint accounting, several factors have consistently been corroborated in the literature. For instance, Shahbaz et al. (2013) and Usman et al. (2020) examined the environmental effect of the patterns of trade and financial development, Alola (2019a, 2019b) incorporated immigration and healthcare in a carbon model. Additionally, energy sources, tourism, globalization, democracy, e.t.c. (Ozturk et al., 2019; Udemba, 2019; Joshua and Alola, 2020). However, considering the lack of empirical study of the impact of risk to investment on environmental quality, the current study incorporates investment profile index vis-à-vis the risk to investment. Thus, the augmented carbon function model employed for this study is presented as

$$\mathrm{ECEM} = f(\mathrm{renep},\ \mathrm{rgdp},\ \mathrm{invest}) \tag{1}$$

Hence, with the exemption of INVEST, the series is transformed to natural logarithm in order to attain direct elasticities and to have an empirical equation in the form of

$$\mathrm{lnECEM}_t = \gamma_0 + \gamma_1 \mathrm{lnrenep}_t + \gamma_2 \mathrm{lnrgdp}_t + \gamma_3 \mathrm{invest}_t + \varepsilon_t) \tag{2}$$

where γ_0 is the constant (intercept) and γ_1, γ_2 and γ_3 are the coefficients that quantify the impact of the logarithm values of renewable energy production (ECEM), real gross domestic product (RGDP) and investment profile (INVEST) on environmental quality for each period t = 1984,

Table 2
Common Statistics and Unit root test with ADF and KPSS.

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera
ECEM	5381.537	5383.716	6005.228	4592.549	414.245	−0.269	2.201	1.7316
RENEP	7037.826	6465.285	11140.20	5161.724	1561.477	1.187	3.200	8.045**
RENEC	7027.547	6464.565	11015.80	5159.918	1538.243	1.171	3.151	7.805**
RGDP	12824.37	13196.53	18108.08	7632.812	3233.882	−0.058	1.645	2.621
INVEST	10.076	11.000	12.000	5.570	2.158	−0.782	2.161	4.460
Observation	34	34	34	34				
Unit root tests			Level			First Difference		
ADF	*with intercept*		*intercept and trend*		*with intercept*		*intercept and trend*	*Conclusion*
lECEM	−1.873		−0.539		−1.723		−6.079*	
lRENEP	0.641		−1.333		−5.439*		−5.897*	
lRENEC	0.598		−1.376		−5.482*		−5.927*	
lRGDP	−1.440		−1.375		−3.446**		−3.679**	
INVEST	−0.667	−2.618			−3.998*		−3.967*	
Lee Strazicich		Level					First Difference	
		Test statistic	Break date			Test statistic	Break date	
lECEM		−6.917**	2004, 2007			−8.351	2004, 2008	
RENEP		−6.809*	1999, 2011			−5.854***	1994, 1997	
lRENEC		−6.927*	1999, 2011			−5.867***	1994, 1997	
lRGDP		−9.740*	1996, 2007			−6.240***	2003, 2007	
INVEST		−12.620	2000, 2003			−10.248	1996, 2005	

Note: The ADF (Augmented Dickey-Fuller) and KPSS (Kwiatkowski–Phillips–Schmidt–Shin) unit root tests. The *, **, and *** are statistical significance at 1%, 5%, and 10% respectively. Also, ecem, renep, renec, and rgdp are the energy carbon emissions, renewable energy production, renewable energy consumption, and the real gross domestic product.

1985, …, 2017 and given that ε is the error term that is expected to be normally distributed with zero mean and constant variance.

3.2. *Empirical methods*

Considering the visual observation (the 'eyeball test') of Fig. 1, it can be inferred that the investigated series have identical long-term characteristics. Importantly, the stationarity test is conducted as a priori test to reveal if the series is stationary at level or not. The unit root methods employed in this context are the (ADF) Augmented Dickey-Fuller by Dickey and Fuller (1979) and the (LS) Lee and Strazicich (2003) unit root tests (see Table 2). While the unit root result from the ADF implies that the all the series are stationary at least at first difference i.e I (0), the LS test result implies that the same but with evidence of break dates. Importantly, the employed LS unit root test accounts for possible break (in this case two break dates) that potentially affects the efficiency of the conventional test approaches such as the ADF. Specifically, result of the LS as indicated in Table 2 revealed that there is a time break in 2011 especially for the case of renewable energy production and consumption. This coincides with the period of unrest i/e the 'Arab spring' that have the potential of posing disturbance to the energy market as a result of the ousting of leaders of Egypt, Tunisia, and Libya. Moreso, both the real gross domestic product and energy carbon emissions expectedly indicate evidence of time break during the global financial crisis (GFC)

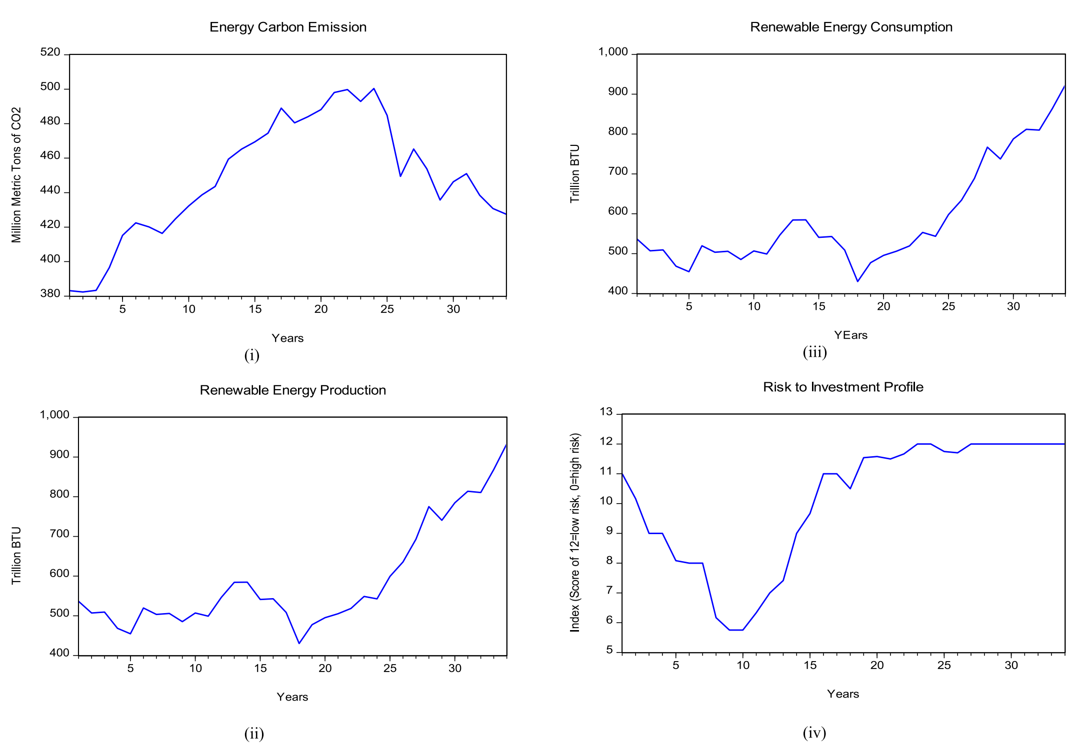

Fig. 1. Time series plot of the examined variables (Years: 1984 =1, 1985 = 2, 1986 = 3, ..., 2017 = 34).

of between 2007 and 2012. However, space constraint has made it impossible to provide the step-by-step procedure for the Dickey and Fuller (1979) and the Lee and Strazicich (2003). In light of the aforementioned evidence, Johansen and Juselius (1990) cointegration test is employed to further corroborate the evidence of long-run relationship as perceived in Figure. Hence, the cointegration result indicated in Table A of the appendix implies that there is a statistical significant evidence of one (1) cointegration equation among the examined series, thus providing econometric basis for applying further cointegration techniques.

3.2.1. Short and long-run

Giving the advantages of the ARDL approach in estimating the periodical cointegration among the series. The appropriateness of the ARDL in estimating both the small and large sample size is an advantage. Also, the ARDL suitable for the current case since the technique is adequate for examining the short and long-run relationships. Similarly, the flexibility of lag selection while employing the ARDL is an additional advantage against other cointegration techniques. The ARDL approach is also found suitable for any order of integration [either I (0) or I (1)] of the variables except for I (2). In this case, the short-run and long-run estimates are simultaneously employed by using the unrestricted ARDL method of Pesaran et al. (2001). Based on the unrestricted error correction model (UECM), the above equation (2) is transformed such that

$$\ln ECEM_t = \lambda_0 + \lambda_1 \ln RENEP_{t-1} + \lambda_2 \ln GDP_{t-1} + \lambda_3 RINVEST_{t-1} + \sum_{i=0}^{q} \theta_1 \Delta \ln ECEM_{t-1} + \sum_{i=0}^{q} \theta_2 \Delta \ln RENEP_{t-1} + \sum_{i=0}^{q} \theta_3 \Delta \ln GDP_{t-1} + \sum_{i=0}^{q} \theta_4 \Delta INVET_{t-1} + \varepsilon_t \quad (3)$$

given that the difference operator Δ is Δxt = xt – xt-1, the λ1, …λ3 and θ1, …θ3 are the impacts of the independent variables in the long and short periods respectively while λ0 is the constant term i.e the long-run intercept. But, in regard to equation (3) above, the speed of adjustment of the energy carbon emissions (especially when there is a shock on the independent variable) from short-run to long-run equilibrium level as presented through the Error Correction Model (ECM) with

$$\Delta \ \ln \ ECEMt = \alpha 0 + \sum_{i=0}^{q} \theta_1 \Delta \ln ECEM_{t-1} + \sum_{i=0}^{q} \theta_2 \Delta \ln RENEP_{t-1} + \sum_{i=0}^{q} \theta_3 \Delta \ln GDP_{t-1} + \sum_{i=0}^{q} \theta_4 \Delta INVET_{t-1} + \chi ECTt - 1 + \varepsilon_t \quad (4)$$

where ECT_{t-1} is the lag of the residuals. Subsequently, the ARDL bound testing approach by Pesaran et al. (2001) is employed such that the null hypothesis of the test is given as $\lambda_1 = \lambda_2 = \lambda_3 = 0$ and the alternative is that $\lambda_1 \neq \lambda_2 \neq \lambda_3 = 0$. Then, the null hypothesis H_0 for the test is given as H_0: $\lambda_0 = 0$ against the alternative of H_1: $\lambda < 0$. Therefore, the result of the ARDL estimate is illustrated in Table 3.

Robustness check with renewable energy consumption

Model B	lrenec	lrgdp	invest	c	ECT (-1)
Long-run	−0.448*	0.495*	−0.014***	7.927*	
Short-run	−0.029	1.269*	−0.004***		−0.302*
Robustness evidence					
				Conclusion	
Bound test: F-statistics = 4.035**	(k = 3)			There is cointegration	
Wald test: F-statistic 11.151*				There is a short relationship	
Residual diagnostics					
Breusch-Godfrey: χ2 (p-value) = 0.375 (0.540)				There is no serial correlation	
Breusch-Pagan-Godfrey: χ2 (p-value) = 8.270 (0.219)				There is Homoskedasticity	
Normalty: Jarque-Bera (p-value) = 1.305 (0.520)					
Skewness				The distribution is positively skewed	

Table 3
ARDL estimate.

Model A	lrenep	lrgdp	invest	c	ECT(-1)
Long-run	−0.443*	0.493*	−0.014***	7.904*	
Short-run	−0.026	1.270	−0.004***		−0.307*
Robustness evidence					
					Conclusion
Bound test: F-statistics = 4.186**	(k = 3)				There is cointegration
Wald test: F-statistic 11.439*					There is a short relationship
Residual diagnostics					
Breusch-Godfrey: χ2 (p-value) = 0.303 (0.582)					There is no serial correlation
Breusch-Pagan-Godfrey: χ2 (p-value) = 8.079 (0.232)					There is Homoskedasticity
Normalty: Jarque-Bera (p-value) = 1.377 (0.502)					There is normal distribution
Skewness					The distribution is positively skewed

Note: Autoregressive Distributed Lad (ARDL) model employed each of the model is (1, 1, 1, 0), the (*p-value*) is the probability value, χ^2 is the Chi-square, SR LM is Serial correlation Lagrange Multiplier, H is Heteroscedasticity, and ECT is the Error Correction Term. The I0 and I1 are lower and upper bound of the bound test respectively, Also, * and *** are the 1% and 10% significant level respectively. The *renep*, *renec*, *rgdp*, and *invest*, are the logarithmic value of renewable energy production, renewable energy consumption, real gross domestic product, investment profile respectively, while l is the logarithmic values.

3.2.2. Test validity with robustness and diagnostic

In order to validate the correctness of equation (2) and the ARDL estimation from equation (3), additional robustness test is employed. In so doing, renewable energy usage is employed in lieu of renewable energy production in the functional equation (2) such that

$$\ln ECEM_t = \gamma_0 + \gamma_1 \ln renec_t + \gamma_2 \ln rgdp_t + \beta_3 invest_t + \varepsilon_t) \quad (5)$$

Subsequently, the implied ARDL estimation is similar to equation (3) and the ECM equation (4) such that every aforementioned procedures for the bound testing are equally applied for this robustness approach.

Additionally, diagnostic tests were employed to validate the results of the estimation. In this case, the coefficient diagnostic such as the Wald test, the residual test for serial correlation by Breusch-Godfrey serial correlation Lagrange Multiplier test, the heteroskedasticity by Breusch Pagan-Godfrey heteroskedasticity test, and the normality test by Jarque-Bera, skewness and Kurtosis were all carried out (see Table 3). Importantly, the Wald test reported a significant evidence of short-run relationship among the estimated variables. Likewise, there is a statistical evidence that the estimated model exhibits a normal distribution and a lack of evidence of both serial correlation and heteroskedasticity for the two cases (i.e with renewable energy production and renewable energy consumption). Furthermore, a stability test through the CUSUM (cumulative sum) and CUSUM of squares of Fig. 2 revealed that the estimated model (from equation (3)) is stable. Moreover, the Cholesky historical decomposition for each of the main variables: energy carbon

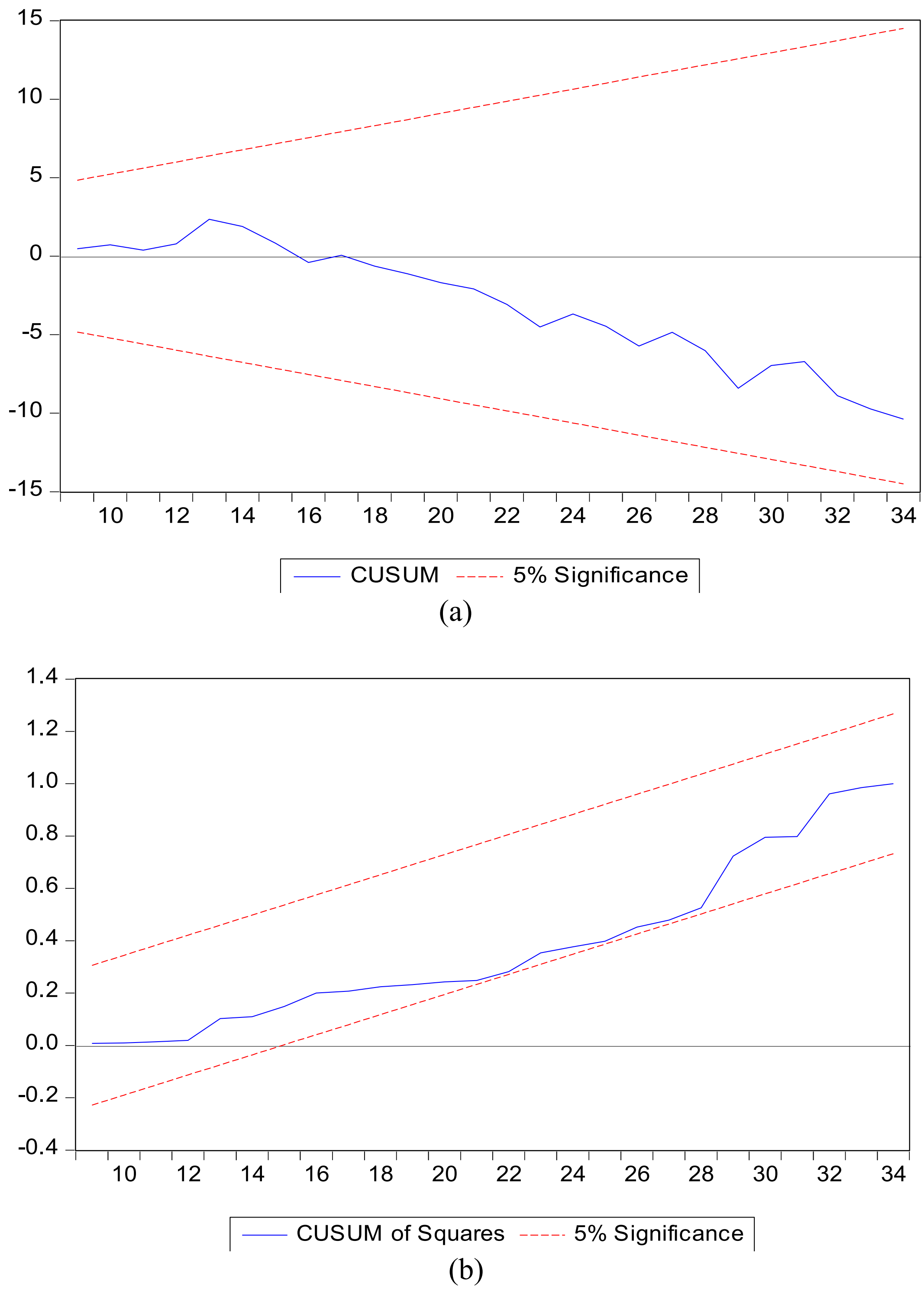

Fig. 2. The CUSUM (a) and CUSUM of Squares (b) stability diagnostic of the model. Note: (Horizontal axis/Years: 1984 =1, 1985 = 2, 1986 = 3, ..., 2017 = 34).

emissions, renewable energy consumption, real gross domestic product, and the risk to investment are illustrated in Fig. 3. Importantly, except in the decomposition of RGDP, there is a significant evidence of distortion in the decompositions of other variables and their associated response.

4. Experimental findings and discussion

Considering the desiring results from the priori and diagnostic tests illustrated in previous sections, the results of the short and long-run estimations presented in Table 3 posits vital information. Specifically, the impact of the risk to investment is interpreted with consideration to the rating adopted for investment profile (INVEST) in PRS. From the results of the short and long periodical time as illustrated in Table 3, it posits that risk to investment (INVEST) exert a negative and significant effect on energy CO2 emissions. The implication is that a 1% increase in the risk to investment (higher rank point correspond to lower risk) is responsible for a respective 0.4% and 1.4% reduction in the Million Metric Tons of CO2 from energy sources in the short-run and long-run. Similarly, the result is relatively the same when the renewable energy usage is used in lieu of renewable energy production as a robustness test.

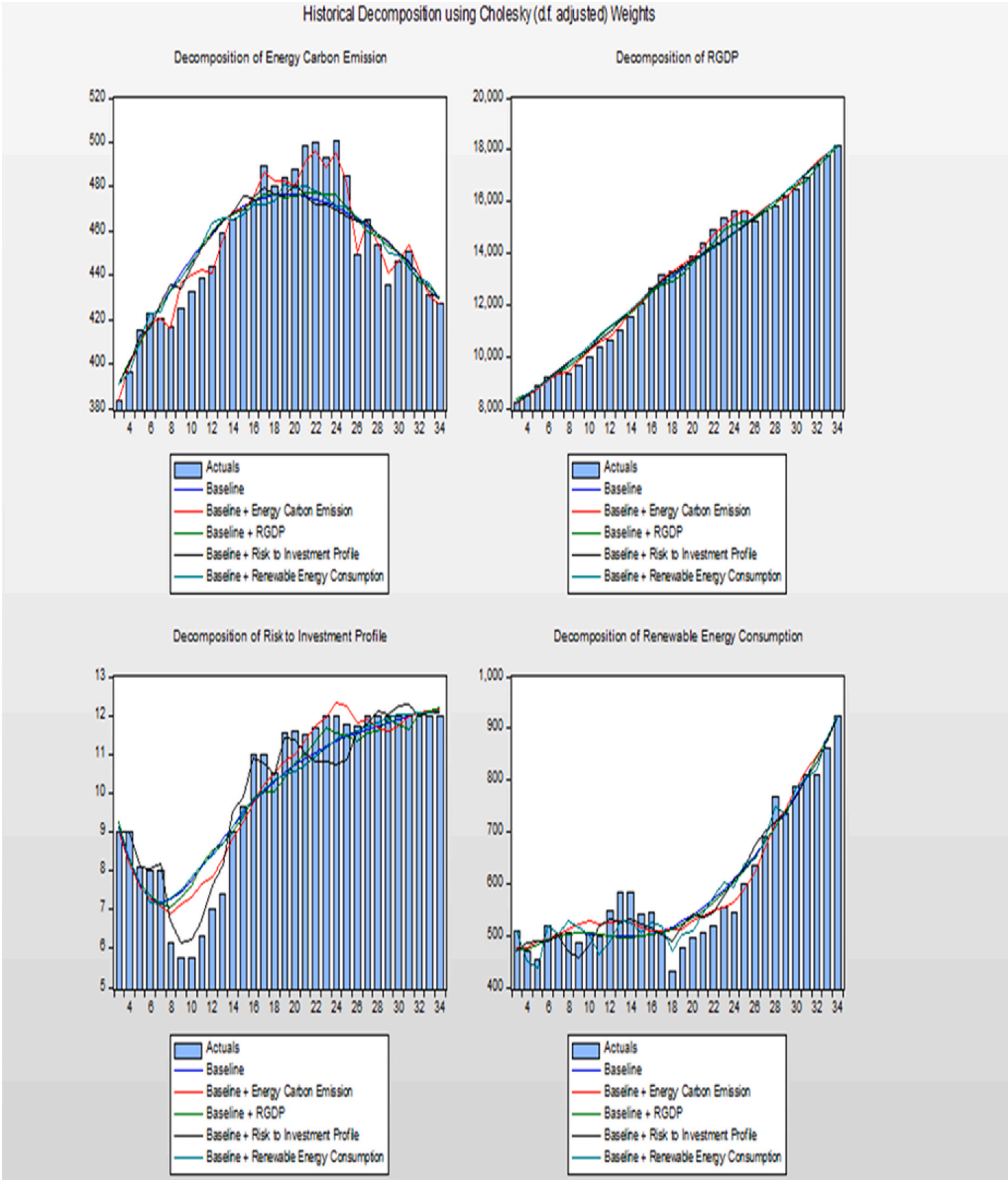

Fig. 3. Impulse Response from each variables to the others.

Desirably, the result suggests that the energy carbon emissions in the United States can be further mitigated by a deliberate attempt to minimize the category of risks associated with low-carbon and clean technologies investments. In affirming the relationship between investment risk and low-carbon energy to ensuring environmental quality, Fuss et al. (2008) and Li et al. (2013) both affirms the source of risk to investment: project risk, volatile prices in the traditional markets, cost is operation period, and construction period. Similarly, Golub et al. (2019) and Benítez et al. (2007) both implied that low carbon emissions are achievable when the country risks that are associated with political, economic and financial factors are significantly accounted for. In the case of the developing countries, Schmidt (2014) identified that investment risk is the bane of low-carbon or carbon neutrality prospects. Specifically, Golub, Lugovoy & Potashnikov (2019) laud the result of the current study by suggesting that the high risk associated with efficient use of energy and technologies for low-carbon in Russia can be minimized through the lowering of country's financial risk and climate and energy policy uncertainties. The study found significant risks in the investment in energy-efficient and new low-carbon technologies, thus quantifying the risk-adjusted cost of capital in the country's energy sector to be about 43%.

Regarding the impact of renewable energy production, the study results opined that energy carbon emission in both the long-run and short-run is reduced as the production of renewable energy increases (see Table 3). Although the impact of renewable energy production in the short-run is insignificant, the long-run impact is statistically significant with an elasticity of 0.443. This translate that a more sustainable environment is achievable by the United States when there is a paradigm shift in the energy portfolio especially toward the development of renewable energy sources. Expectedly, when renewable energy consumption is employed in the model in lieu of the renewable energy production, a similar result is presented but the long-run elasticity of the impact of renewable energy consumption becomes 0.448 (see lower part of Table 3). Several studies with different cases have suggested that renewable energy consumption enhances environmental sustainability (Ozturk and Acaravci, 2010; Ahmad et al., 2020; Nathaniel and Iheonu, 2019). Notwithstanding, the contribution of renewable energy consumption to environmental quality has either been considered insignificant or statistically significant and undesirable in other literature (Nathaniel, Anyanwu & Shah, 2020).

Additionally, the result depicts that economic growth vis-à-vis the increase in the GDP is responsible for the degradation of environment in the long and short terms in the United States (see Table 3). Specifically, a 1 percent increase in the GDP will cause a statistically significant of 0.493 percent increase in the Million Metric Tons of CO_2 in the long-run which is a reduction in the short-run impact of 1.270 percent. It implies that although the impact of economic growth on environmental quality in the long-run is not desirable, it is not as worse as the short-run impact. Thus, suggesting an improvement on environmental quality as the economy improves. Nonetheless, when the renewable energy consumption is employed lieu of renewable energy production, the implication is the same with the previous scenario (lower part of Table 3). The study of Usman et al. (2020) also detailed the relationship between economic growth (GDP) and environmental quality. As indicated earlier, these aforementioned and outlined results that presents the nexus of the estimated variables has been verified through a series of diagnostic tests.

5. Conclusion and policy reflections

Considering the associated bottlenecks and hindrances stalling the attainment of global environmental sustainability, more details are currently being giving to the relatively salient factors and micro elements. The exigencies of the containment to net-zero carbon emissions approach of the developed economies such as the case the United States necessitate the investigation of the role of risk to investment in environmental sustainability in the current scenario. While examining the role of risk to investment in the current study, the impacts of economic development (real GDP) and renewable energy production is alongside examined over the experimental period of 1984–2017. Importantly, the result from the investigation revealed some interesting perspectives. Accordingly, (1) it is revealed that a lowered risk to investment in the United States is an essential factor to be further considered in driving the country's environmental quality targets. Expectedly, this is true because reduction in risk associated with investment in businesses such as in energy technologies, production and manufacturing companies and other climate financing will translate to moving away from the business-as-usual to the adoption of a more environmental-friendly approaches. (2) Again, the result of the investigation posits that economic development (RGDP) worsen the environmental quality, thus an undesirable carbon effect of economic expansion is inherent in the country. (3) Lastly, both the production and consumption of renewable energy expectedly observed as one of the pathways to environmental sustainability in the United States.

5.1. Policy implication

In line of the result, this study presents a handful of policy directives and recommendation for the stakeholders from the perspective of cleaner production and environmental sustainability. Considering the impact of risk to investment to environmental sustainability as posited in the study, policy should be further directed at providing and guiding investors on risk assessment, thus minimizing potentially high risk associated with low-carbon energy investment and market. Since there is no differential impact from production and consumption of renewable energy, it implies that the current effort regarding the country's energy transition is in the right direction, thus it should be further strengthened. However, the current study is limited because it does not specifically consider the risk associated with energy investment. Hence future research can complement this study by employing the impact of energy investment risk on environmental quality.

CRediT authorship contribution statement

Andrew Adewale Alola: Writing – original draft, Investigation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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